NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Goddard Space Flight Center

S.R. Number 034

"Made available under NASA sponsorship
in the interest of early and wide dis-
semination of Earth Resources Survey
Program information and without liability
for any use made thereof."

STUDY OF TECHNIQUES AND APPLICATIONS OF ERTS IMAGERY TO SMALL SCALE MAPPING

March 1975

HUNTING SURVEYS LTD
Elstree Way
Boreham Wood
Herts.
England

I

SR No. 034

Study of Techniques and Applications of
Satellite Imagery to Small Scale Mapping.

Mr. P.G. Mott. B.A., F.I.C.E., F.R.I.C.S.
Hunting Surveys Ltd.,
Elstree Way,
Boreham Wood,
Herts,
England.

Final Report

Department of Trade and Industry,
Prospect House,
100, New Oxford Street,
London,
WC1A 1HE,
England.

1. SR No. 034 2. *Type of Report* III	3. Recipient's Catalog No.
4. Title. Study of Techniques and Applications of Satellite Imagery to Small Scale Mapping.	5. Report Date 1st March 1975 6. Period Covered July 1972 to February 1975
7. Principal Investigator Mr. P.G. MOTT B.A., F.I.C.E., F.R.I.C.S.	8. No. of Pages
9. Name and Address of Principal Investigator's Organisation. Hunting Surveys Ltd., Elstree Way, Boreham Wood, Herts, England.	10. Principal Investigator's Report No. 11. GSFC Technical Monitor Mr. J.C. Broderick
12. Sponsoring Agency Name and Address Department of Trade and Industry, Prospect House, 100, New Oxford Street, London, WC1A 1HE, England.	13. Key Words (Selected by Principal Investigator) Cartography Small Scale Mapping
14. Supplementary Notes	

15. Abstract

AN EVALUATION OF ERTS-1 IMAGERY FOR SMALL SCALE MAPPING

The application of ERTS-1 imagery to small scale topographic mapping at one in a million scale was evaluated using the United Kingdom as the test area. The geometric accuracy of the imagery was found to be suitable for one in a million scale mapping using simple block adjustment procedures given a sparse network of identified ground control points. The interpretation of topographic detail in two test areas was inadequate for mapping at this scale without additional sources of information. ERTS-1 imagery is already proving itself useful as a map-substitute, either as controlled mosaics or map compilation. In the remoter inadequately mapped parts of the world ERTS imagery may provide an economic method of preparing a geometrically sound base-map with skeletal detail upon which to hang topographic information from other sources.

SUMMARY

Discipline - 2. Land Use Survey and Mapping

Sub-discipline B. Orthographic Mapping

The purpose of this study was to evaluate the possible applications of ERTS-1 imagery to topographic mapping at around 1:1,000,000 scale. The United Kingdom was selected as the test area because of the reliability of topographic ground truth data readily available in the form of Ordnance Survey maps at all scales.

Tests of the internal geometric accuracy of MSS systems corrected imagery gave a root mean square error of 153 metres on individual images. These individual images were joined together to form a block and this was found to have a r.m.s.e. of 179 metres with a maximum error of 370 metres when compared to control coordinates.

Various image interpretation techniques were investigated and compilations produced of two test areas. The compilations were found to have a r.m.s.e. on detail position of 272 metres. Detail content of the imagery was found to vary considerably and it was not possible to extract all the detail necessary to produce a map at 1:1,000,000 scale. However, sufficient detail could be extracted to produce a geometrically sound frame-work which could be augmented by detail from other reliable sources.

The imagery in the form of photographic enlargements has been found useful for field and aircraft navigation in areas where no reliable maps exist.

Principal Investigator

Mr. P.G. Mott, B.A., F.I.C.E., F.R.I.C.S.
Hunting Surveys Ltd.

Co-investigators

Mr. H. Fullard, M.Sc.
George Phillip & Son, Ltd.

Mr. J.C. Bartholomew, M.A., F.R.S.E.
John Bartholomew & Son, Ltd.

Mr. J.D. Leatherdale, B.A., B.Sc., A.R.I.C.S.
Hunting Surveys Ltd.

Mr. H.J. Chismon
Hunting Surveys Ltd.

Mr. J.K. Wilcox
Hunting Surveys Ltd.

CONTENTS

FIGURES

ILLUSTRATIONS

1. INTRODUCTION

The purpose of this study was to evaluate the possible applications of ERTS-1 imagery to topographic mapping at around 1:1 million scale. Many of the remoter regions of the world are not mapped to acceptable standards even at this scale and there is a real need to find economic techniques for original mapping and updating of mapping at 1:1 million scale in these areas for which purpose ERTS imagery might to some extent be applicable. Other more simple applications in the general field of navigation and cartography became apparent during the investigation.

For the application of ERTS imagery to topographic mapping to be successful, the geometric accuracy of the imagery must be acceptable, the level of interpretation of topographic detail must be adequate and economic methods of map production must exist or be developed which compare favourably with conventional techniques in cost and quality of the final map product. To make these assessments, tests were carried out to determine the geometric accuracy of the imagery and the levels of completeness and reliability of interpretation of topographic features which could be obtained. After initial familiarisation with the imagery and experiments with various techniques for interpretation and map compilation, a number of practical methods of map production evolved.

Bulk or systems corrected imagery had to be used for all these tests as the precision or scene corrected imagery requested was not forthcoming. This was not a practical disadvantage as the mapping of the remoter parts of the world, where ERTS imagery may be applicable, would have to be accomplished with a much sparser density of ground control stations than scene processing demands. Only Multispectral Scanner imagery was available as the Return Beam Vidicon recording system failed soon after launch. Greater geometric accuracy had been expected from the RBV system.

The whole of the United Kingdom was selected as the test area because of the reliability of topographic ground truth data available in the form of Ordnance Survey maps at all scales augmented where necessary by data of our own. Predictably complete coverage of the United Kingdom was never obtained because of the climate and very few frames were duplicated on different dates. The quality of the imagery of the United Kingdom is poor compared with examples of regions with less atmospheric

haze, humidity and air pollution. This provides a cautionary reminder that many of the most inadequately mapped regions of the world are obscured by persistent cloud which remote sensing in the visible spectrum cannot penetrate.

2. SUMMARY OF INVESTIGATION

2.1 Geometric Accuracy

Tests of the geometric accuracy of MSS systems corrected imagery were carried out to determine the magnitude of errors of internal location, scale, orientation and positioning of the marginal graticule cuts of individual frames.

2.2 Block Adjustment

A simple photogrammetric block adjustment was performed using six adjacent frames which were connected by tie points and adjusted onto a network of identified control points in order to develop a suitable procedure for mapping large areas using a sparse network of ground control stations.

2.3 Interpretation of Imagery

An investigation was made into the interpretation of topographic details. Techniques considered included binocular viewing of different spectral bands, density slicing and colour additive viewing. At this stage, reference was made to other sources of information to check the accuracy of the interpretation. An evaluation of the four spectral bands was made to discover which bands or combination of bands were best suited for interpreting the various types of detail. An 'unseen' interpretation of the imagery of two test areas was made for use at the compilation stage of the study.

2.4 Map Compilation

Compilations of the two test areas were produced by different methods. These were investigated for positional accuracy and content of detail. Possible methods of using the imagery to portray relief were considered and trials made.

2.5 Presentation and Assessment of Results

The compilations of the two test areas were fair drawn and reproduced with comparative ground truth material. The results were assessed and preliminary conclusions drawn about the application of ERTS to small scale topographic mapping.

3. TESTS OF GEOMETRIC ACCURACY OF MSS SYSTEMS CORRECTED IMAGERY

3.1 Selection of Imagery

For this test, a block of six images in the eastern half of England was chosen. No account was taken of the date of the imagery, the criteria for selection being quality of image and freedom from cloud cover.

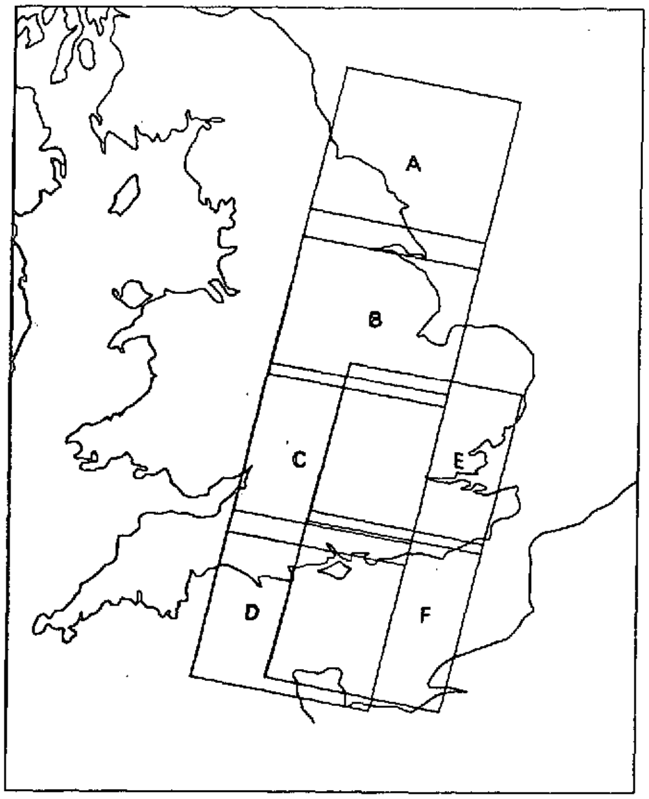


FIGURE 1

A. E - 1229 - 10343

B. E - 1031 - 10334

C. E - 1229 - 10352

D. E - 1229 - 10354

E. E - 1228 - 10293

F. E - 1228 - 10300

3.2 Dimensions of Images Used

Since it was considered desirable to keep the materials supplied by NASA unmarked, copies were made for these tests. Contact negatives on glass were made from the NASA 1:1,000,000 film positives and from these glass diapositives were produced. Comparisons were made to check the dimensional accuracy of the glass diapositives and they were found to be about 0.02mm smaller than the film positives.

Figure 2

Comparison between Dimensions of NASA Film Positive and Glass Diapositive

Distances measured between corner registration crosses. Image No. E - 1228 - 10293.

	Film		Glass	Diff
Top	198.47 mm.	Top	198.44 mm.	-0.03 mm.
Bottom	198.04 mm.	Bottom	198.02 mm.	-0.02 mm.
Left	204.13 mm.	Left	204.11 mm.	-0.02 mm.
Right	204.33 mm.	Right	204.32 mm.	-0.01 mm.

Comparisons were also made between the spacing of the registration marks on each image and the NASA published dimensions. No relationship between these various dimensions could be found, although the measured distances were consistently large (see Fig.3.). From this, it was concluded that measurements taken from the marginal markings are not a true indication of variations in scale of the images.

Figure 3

Dimensions of Image Marginal Markings

Differences of registration mark spacing measured on six images and expressed as percentages of NASA published dimensions.

	Mean %	Min.% - Max.%
North side	100.42	100.25 - 100.71
South side	100.64	100.46 - 100.86
West side	101.54	100.95 - 101.99
East side	101.46	101.00 - 101.84

3.3 Ground Control

The ground control was taken from the Ordnance Survey 1:63360 (1 inch to 1 mile) map series. A density of control was chosen which gave

nine equally displaced points on a full image, with a reduced number on those images which included areas of sea.

Points of map detail which were clearly visible on the imagery were selected and the positions of the points were marked on the diapositives by drilling a 40 micron hole in the emulsion. The points of detail chosen were always either the intersections of airfield runways or water features such as the junctions of canals or corners of reservoirs, these being the types of detail which are most clearly and consistently visible.

The Ordnance Survey one inch maps in south and eastern England are compiled from reductions of the basic survey which is at 1:2,500 with 1:1,250 in urban areas. There are no published accuracy specifications for these maps, but from our extensive user experience of the maps at basic survey scales we have found the precision to be better than ± 3 metres with occasional errors in rural areas of twice this figure. At 1:63,360 scale survey errors of this magnitude are unplottable, but errors in compilation, colour separation and in the generalisation of detail inevitably reduce the accuracy of coordinates scaled from these maps. The coordinates of a random selection of points were measured on both map series and compared. The maximum difference found was ± 25 metres (see Figure 4). From these results we consider the plan coordinates of points of detail read from the OS one inch map series to be accurate to ± 35 metres which is more than adequate for testing the accuracy of the imagery.

Figure 4

Comparison Between OS 1:2,500 and 1:63,360 Maps to Determine Accuracy of Control Coordinates

	1:2,500		1:63,360			
	E	N	E	N	Δ E	Δ N
1	513003	434313	513000	434293	3 m	20 m
2	502688	218240	502695	218216	7 m	24 m
3	600670	213740	600665	213743	5 m	3 m
4	502152	191517	502132	191509	20 m	8 m
5	624677	146817	624689	146832	12 m	15 m

3.4 Measurements

Plate coordinate of identified points were measured using a Wild A7 stereoplotter with automatic read-out of coordinates on punched tape. The instrument was used as a monocomparator and the coordinates of the control points were recorded in millimetres at a scale of 1:500,000. The instrument had previously been calibrated to ensure an exact enlargement of 1 to 2 between the image scale and the measurement scale and was found to be accurate to $\pm$ 20 microns at the image scale, giving a maximum instrumental error of 20 metres.

3.5 Adjustment

The coordinates measured and recorded on the Wild A7 were adjusted to a least squares fit onto the control coordinates. Each image was treated independently and the instrument coordinates were subjected to a rotation, change in origin and change in scale.

3.6 Ordnance Survey Datum

Control coordinates were taken from the OS maps. These coordinates are on the Ordnance Survey National Grid, the parameters of which are as follows:

Projection: Transverse Mercator

Airy Spheroid

a = 6377563.396 m

e^2 = .0066705400000123428

Scale on central Meridian

= 0.9996012717

Latitude of origin = 49°N

Longitude of origin = 2°W

False eastings of origin = 400,000 m

False northings of origin = -100,000 m

Relationship to European Datum at Herstmonceux:

OSGB (1936) Datum

Latitude 50° 51' 55.271" N

longitude 00° 20'45.882" E

N_o = -1 metre

European Datum International Spheroid:

Latitude 50° 52' 00.525" N

Longitude 00° 20' 44.943" E

N_{o} = -6 metres

3.7 Scale Errors

The scale of each image was found by comparing a distance computed from the instrument coordinates with a comparable distance taken from the adjusted coordinates.

Image No.	Scale of Image
E - 1031 - 10334	1:997,961
E - 1228 - 10293	1:1,000,305
E - 1228 - 10300	1:998,535
E - 1229 - 10343	1:1,000,340
E - 1229 - 10352	1:998,027
E - 1229 - 10354	1:998,050

The largest scale error is 2 parts in 1,000 and this is equivalent to an error of 370 metres in the full width of an image.

No relationship could be found between the scale of the images and the marginal detail dimensions recorded in Figure 3.

3.8 Location Errors

A total of 36 control points were used to fit the six images to the ground. The residual plan errors were as follows.

Image	No. of Points	r.m.s.e.	
E - 1031 - 10334	5	238 metres	
E - 1228 - 10293	11	161 metres	(Figure 5)
E - 1228 - 10300	3	81 metres	
E - 1229 - 10343	4	134 metres	
E - 1229 - 10352	9	137 metres	(Figure 6)
E - 1229 - 10354	4	43 metres	
Total	36	153 metres	

Distribution of Errors

Residuals	No. of Points	Percentage of Points
0 - 49 metres	6	17 per cent
50 - 99 metres	14	40 per cent
100 - 149 metres	3	8 per cent
150 - 199 metres	6	17 per cent
200 - 249 metres	2	5 per cent
250 - 299 metres	3	8 per cent
300 - 349 metres	2	5 per cent

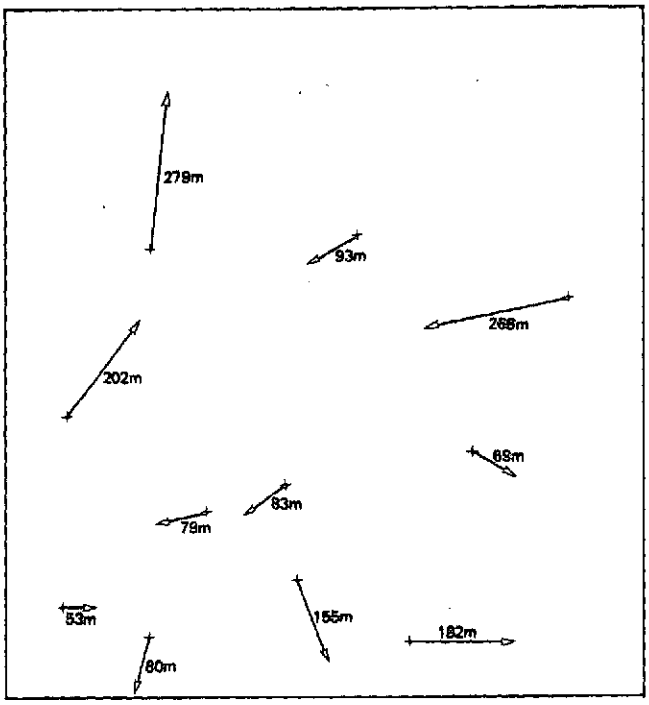


FIGURE 5
Errors on control points
Image E-1228-10293
r.m.s.e. 161m

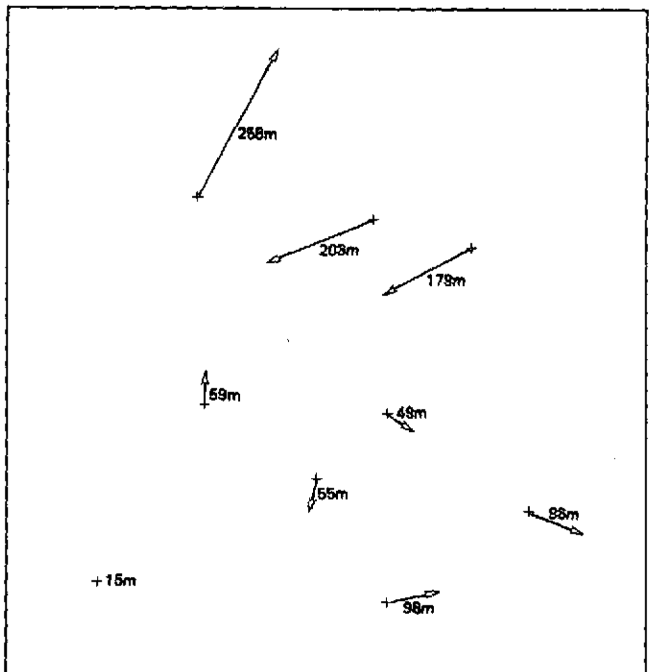


FIGURE 6
Errors on control points
Image E-1229-10352
r.m.s.e. 137m

4. CONSTRUCTION OF A BLOCK OF IMAGERY

4.1 Block Adjustment

The mapping of large areas involves matching adjacent frames and part frames of different dates. This problem, which is common to conventional photogrammetry, can be solved by aerial triangulation procedures which connect photo models together in blocks and adjust them simultaneously to obtain a best fit onto identified control points. Tests were carried out using simplified block adjustment procedures to determine whether accuracies acceptable for 1:1 million scale mapping could be achieved with the imagery.

The positions of the marginal graticule ticks were also checked to ascertain whether they could be used to augment or even replace sparse or inadequate ground control.

4.2 Selection of Imagery

The same imagery was used for the block construction as had been previously used for the tests of geometric accuracy of single frames.

4.3 Construction of the Block

The individual images were joined together by means of tie-points, there being four points along the common overlap between each image. This number had of course to be reduced where the images included areas of sea. These tie-points were marked on the diapositives by drilling a hole in the emulsion of one diapositive and the position of that hole was then transferred binocularly to the adjacent image. The accuracy of transfer therefore depends upon the binocular fusion of a small area of image and is not seriously affected by contrast and density differences between the two images which might otherwise cause apparent differences of position of individual points of detail.

4.4 Graticule

In order to check the accuracy of the positioning of the graticule ticks along the margins of the images, it was first necessary to project the lines of latitude and longitude to find the positions of the points of intersection. To do this, a graticule on the O.S. National Grid Projection was constructed for each image and this was superimposed on the glass diapositives. It was found to fit the graticule ticks to within 400 metres.

4.5 Measurement of Images

The same methods were used for this as had previously been used in the tests for geometric accuracy. Instrument coordinates were read of all control points, tie-points and a random selection of graticule intersections.

4.6 Adjustment

The adjustment of the block was performed using a standard photogrammetric procedure known as 'Independent Model Aerotriangulation'. Each model (image) was subjected to a scale change, azimuth rotation and translation onto the tie-points of the adjacent models. This iterative process was repeated until the whole block was gradually 'settled' model by model into a best fit position. The block was then fitted on the ground control points. The whole procedure was then repeated as many times as were necessary to produce a satisfactory least squares solution.

Except where local differences in relief exceed 1000 metres, the planimetric errors introduced by height differences between control points can safely be ignored.

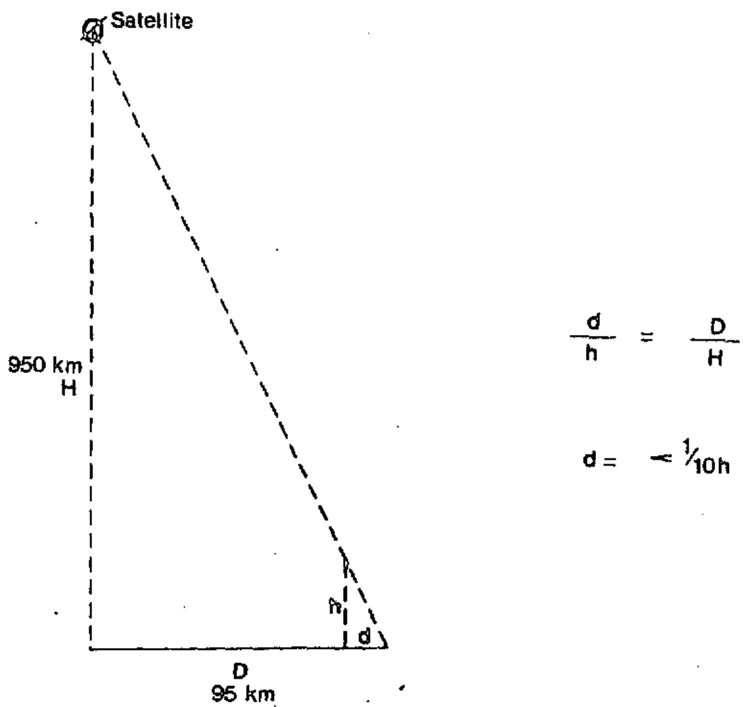


Figure 6a Effect of ground height on plan position of detail

At worst the displacement is only one tenth of the height difference. In the test area the height differences were only 150 metres.

4.7 Fit of Tie-Points (see Figure 7)

The individual images fitted together very well, giving a root mean square error (r.m.s.e.) of 86 metres on a total of 46 tie-points. The maximum error was 171 metres.

Distribution of errors

Residuals	No. of Points	Percentage of Points
0 - 49 metres	12	26 per cent
50 - 99 metres	22	48 per cent
100 - 149 metres	11	24 per cent
150 - 199 metres	1	2 per cent

The residual error on the tie-points is calculated from the mean of the adjusted coordinates.

4.8 Fit onto Control Points (see Figure 8)

As expected, the fit of the block onto control points was not as good as the fit of the individual images onto the same control, giving a r.m.s.e of 179 metres on a total of 31 points. The maximum error was 370 metres.

Distribution of errors

Residuals	No. of Points	Percentage of Points
0 - 49 metres	7	23 per cent
50 - 99 metres	7	23 per cent
100 - 149 metres	4	13 per cent
150 - 199 metres	6	18 per cent
200 - 249 metres	0	0 per cent
250 - 299 metres	3	10 per cent
300 - 349 metres	3	10 per cent
350 - 399 metres	1	3 per cent

4.9 Residual Errors on Graticule Intersections

The residual errors on the graticule intersections were found to be very much greater than the forecast positional mapping accuracy of approximately 750 metres. The maximum error found was 5,100 metres and the minimum was

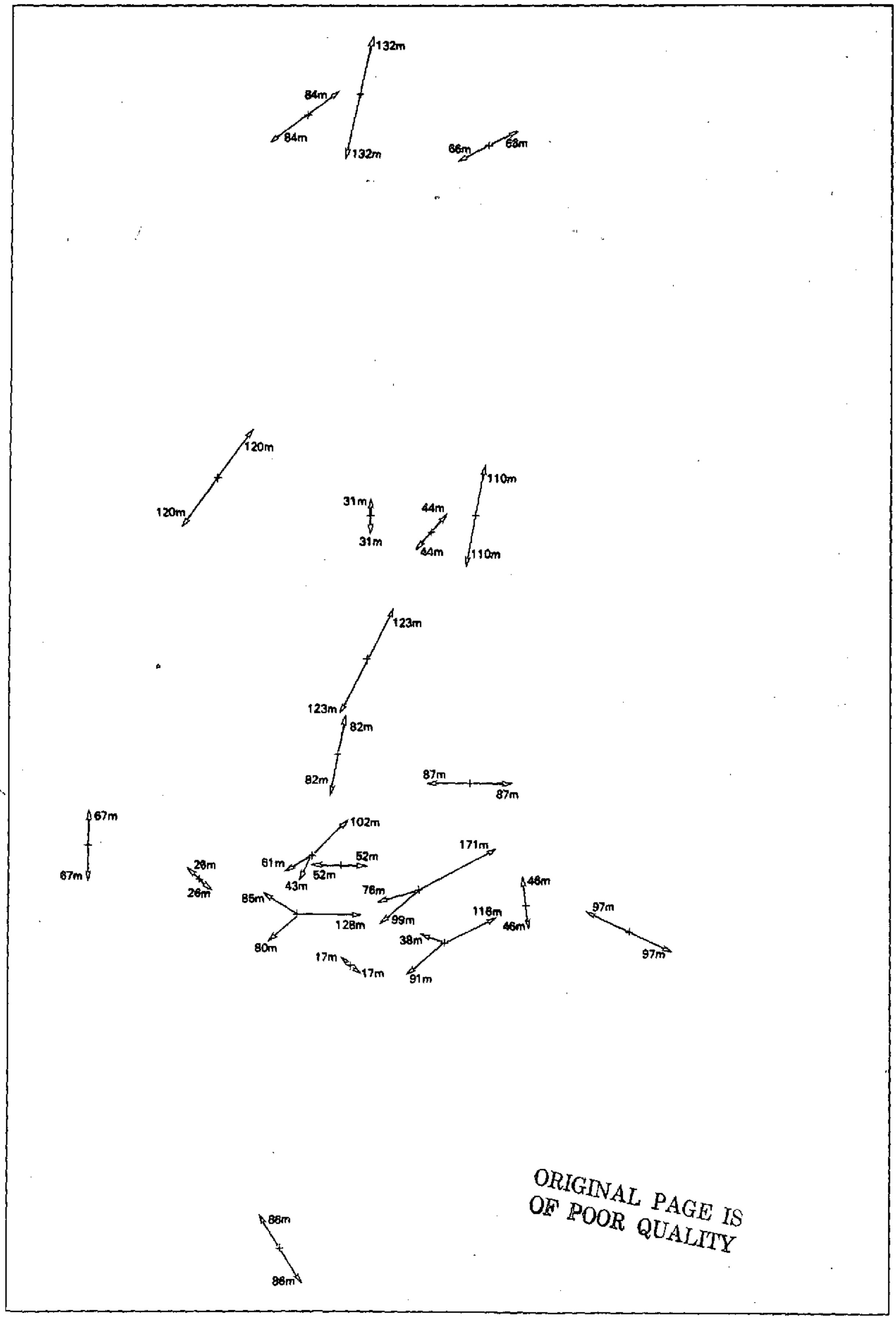


FIGURE 7
Errors on tie-points after block adjustment

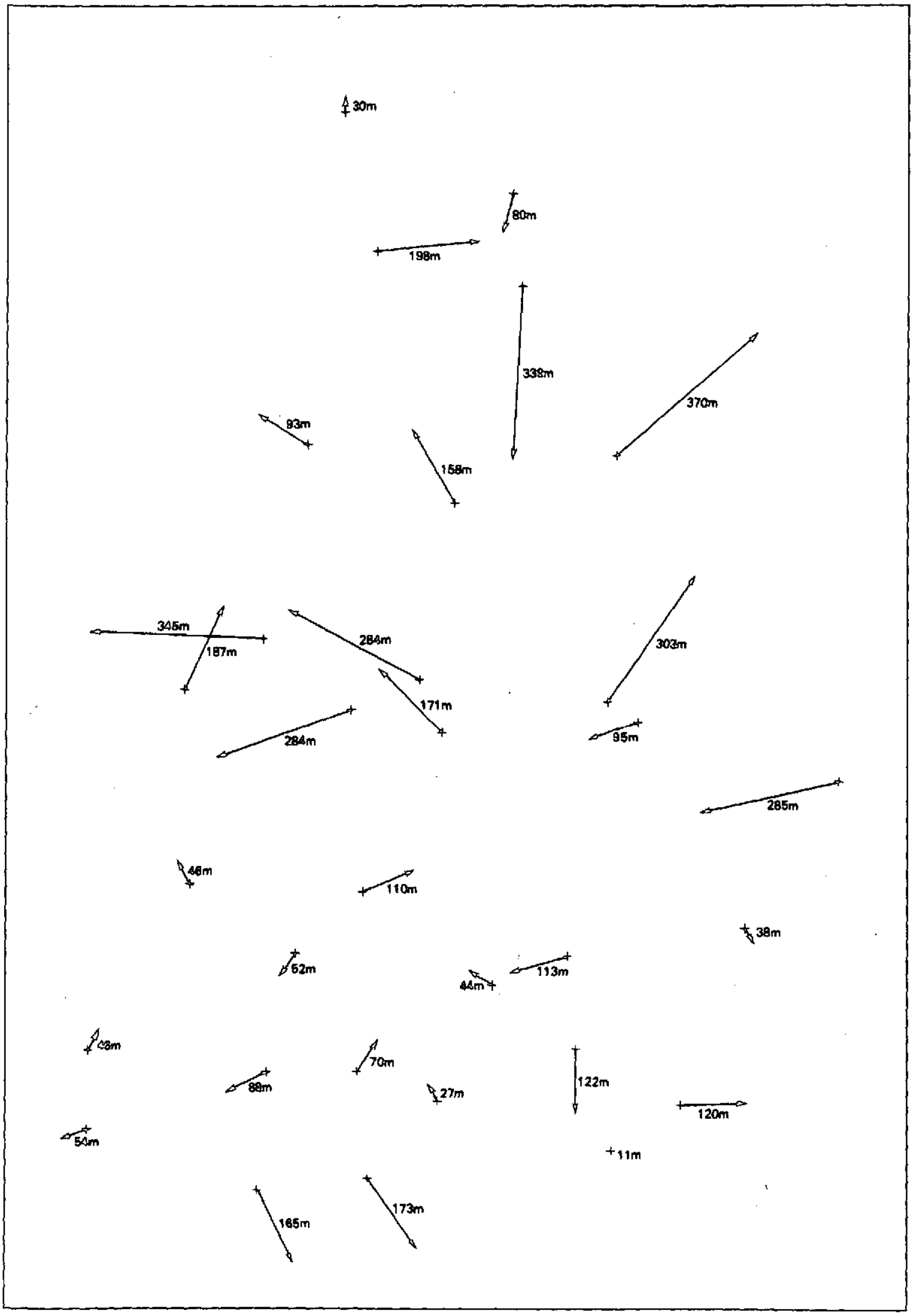


FIGURE 8
Errors on control points after block adjustment

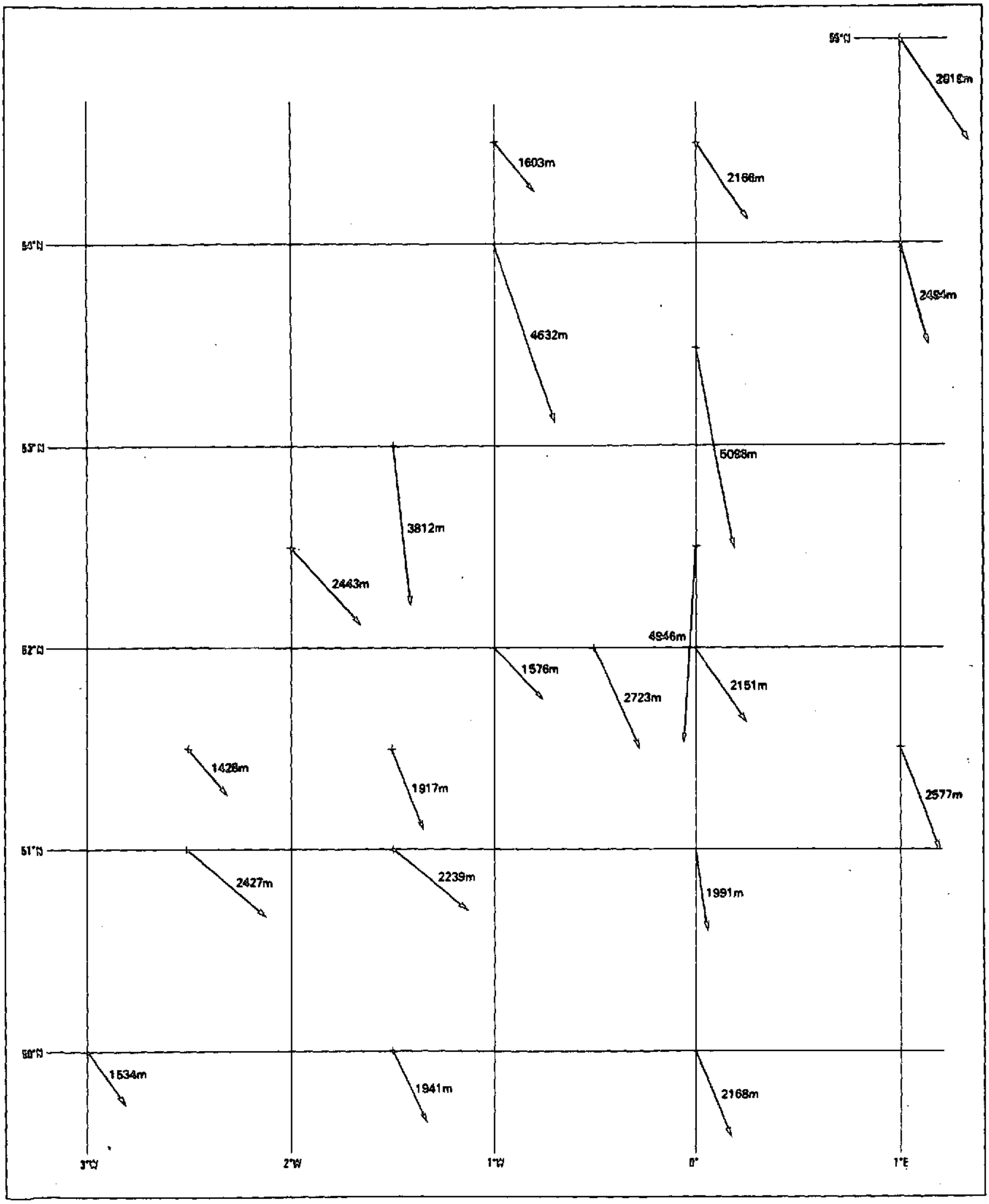


FIGURE 9
Errors on Graticule Intersections after Block Adjustment

1,400 metres. It is notable however that there is a common pattern apparent in these errors. (See Figure 9)

Five of the images, all of which were taken on days 228 and 229 show a very similar displacement of the graticule. This displacement is almost constant in direction and distance. The sixth image shows a very much greater displacement, although the direction is still similar. (See Figure 10). It appears from this that, subject to further confirmation in the area of interest, it should be possible to use the graticule ticks to obtain a reasonable orientation of a block, although they could not be used for scale or absolute position. The results would probably be better if the graticule ticks used for this were all on images taken on or around the same date.

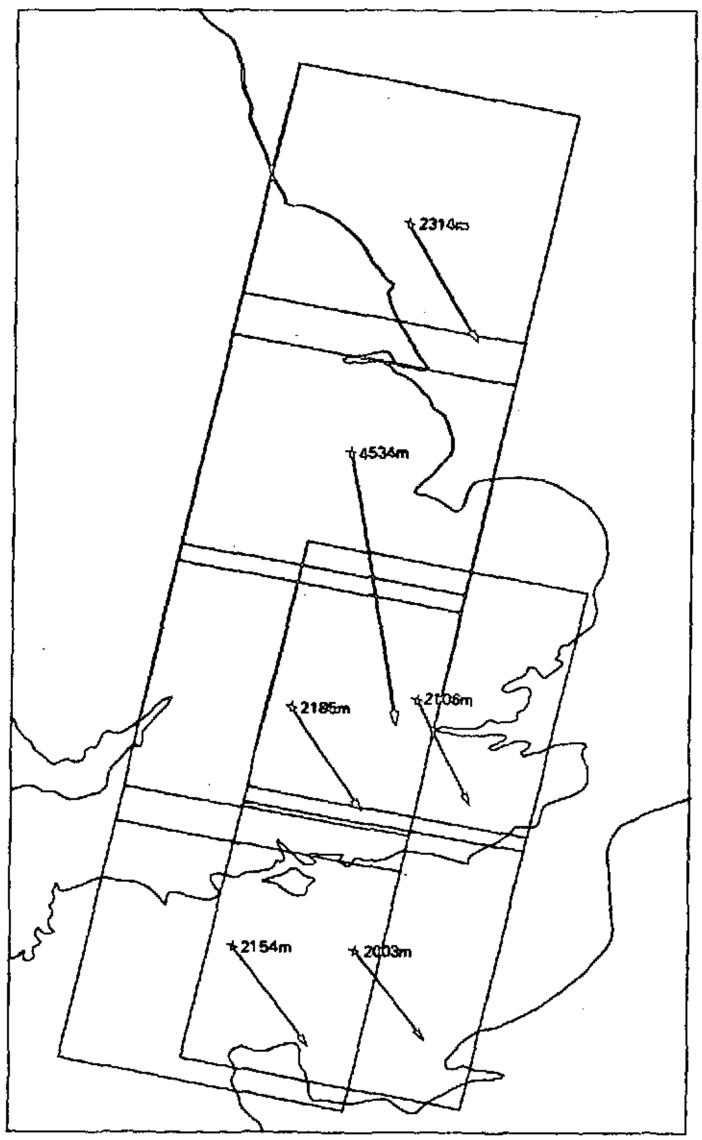


FIGURE 10
Mean errors on graticule intersections on each image

4.10 Assessment of Results

In order to assess the acceptability of the results of the geometric tests and block adjustment it is necessary to define the planimetric accuracy acceptable for 1:1 million scale mapping. As most mapping at this scale today has either been compiled from larger scale rigorous mapping or from admittedly inadequate information, no general consensus of standards of accuracy at this scale has evolved. Taking into account the cartographic generalisation involved at this scale, and the purposes for which 1:1 million maps are used, it is doubtful whether the normal standards of 'plottable accuracy at publication scale' apply. However as a base line is needed for comparison it seems reasonable to take an r.m.s.e. of ± 0.3 mm at publication scale, which is equivalent to the U.S. National Map Accuracy standard of 90 per cent of points within 1/50 inch. At 1:1 million scale this represents an r.m.s.e. of ± 300 metres on the ground.

The results of this block adjustment suggest that accuracies acceptable for 1:1 million scale mapping can be achieved given sufficient density of identified ground control points. As block adjustment of ERTS imagery is most likely to be used in remote and inadequately mapped areas where ground control is sparse or lacking and expensive to establish, the economy of the method will depend upon being able to obtain acceptable accuracies with quite large blocks using a small number of widely spaced control points. The fragmented cover of the United Kingdom prevented the observation of a large block which is necessary to prove the method. However the results achieved with the six model block are sufficiently encouraging to suggest that acceptable results will be obtained with a fairly sparse density of control.

5. INTERPRETATION OF IMAGERY

5.1 Methods of Interpretation

From the severely limited coverage of the United Kingdom which was supplied, two test areas were selected for interpretation unaided by ground truth data. Before undertaking the unseen interpretation of these areas, other frames were interpreted using every available aid to gain experience in interpreting the imagery.

The approach to the interpretation of the ERTS Imagery is somewhat different to that employed in the interpretation of conventional aerial photography. When using normal aerial photography, the interpreter spends most of his time on the identification and delineation of specific and usually easily definable details. On satellite imagery, most individual details are too small to be separately delineated, even when they contrast sufficiently with their surroundings to be visible. Much of the interpreter's time is spent in trying to evaluate and define the limits of vague and ill-defined image patterns.

The choice of the United Kingdom as the test area for this study was based upon the ready availability of accurate and up-to-date ground truth data. It has however caused problems with the interpretation. Stated simply, there is too much detail. The irregular pattern of small fields and villages tends to confuse and obscure fine detail and the intensive nature of the cultivation often obscures natural features which would otherwise be visible (See illustration 1).

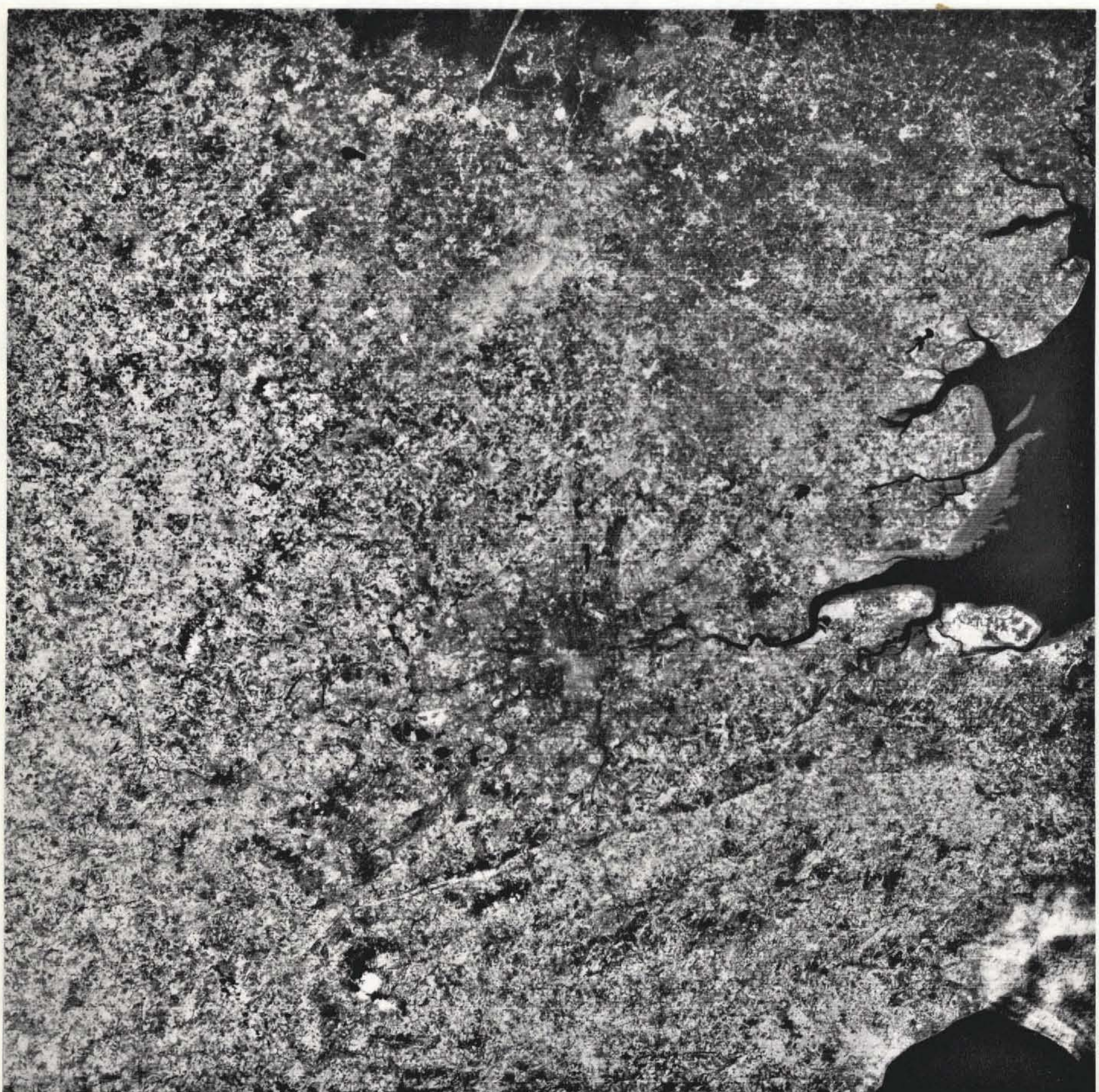
The images used in conjunction with O.S. maps for the initial investigation into interpretation techniques were in other areas to those selected for the compilation test in order to maintain the 'unseen' nature of these tests.

It must be emphasised that the following comments on interpretation are based upon the interpretation of imagery of the U.K. and must therefore be influenced to a great extent by local conditions. Whilst they must be of help in the interpretation of images of other parts of the world, it should not be assumed that all conclusions are universally applicable.

5.2 Use of Colour Products

Colour products were found to be very useful for the recognition of areas of cultivation and vegetation changes. Most use was made of 1:1,000,000

Image E-1228-10293-6. Scale 1:1,000,000



This illustrates the dense overall development pattern in S.E. England which completely obscures most natural topographic features.

scale false-colour combination paper prints. It was found that the colour prints supplied by NASA varied greatly in colour and density and it was necessary to make new colour prints to meet our own requirements.

Tests were carried out with a multispectral viewer (International Imaging Systems - Model 600 - Additive Colour Viewer). It was found that this gave no great advantages. Any details which could be identified on the viewer could also be identified by an experienced interpreter using simpler and very much less costly equipment. Finer details are lost in the viewer due to the optical system and the ground glass screen onto which the images are projected.

5.3 Density Slices

Density slicing has been of little use for the interpretation. Areas of interest are usually too small and the variations in density too slight for simple slicing techniques to give meaningful results. Those details which have been successfully 'sliced-out' can also be interpreted by other simpler methods. There is also the problem of wide variations in image density within certain types of detail which would effectively preclude the general use of this technique for their interpretation.

5.4 Use of Black and White Products

The most useful form of imagery for interpretation purposes is undoubtedly 1:1,000,000 scale black and white paper prints. Different spectral bands can be viewed binocularly under a stereoscope and variations in image density between the bands cause many details to stand out quite distinctly. There is of course no stereoscopic effect of relief when this method is used, but the use of the stereoscope allows a small degree of magnification, as well as greater viewing comfort for the interpreter. A small hand stereoscope was preferred for this, but a larger mirror stereoscope could be used just as well. The preference was probably due to the personal choice of the interpreter, rather than to the relative merits of the two types of stereoscope.

Half million scale enlargements of the black and white images were found useful in the recognition of linear features. When these are viewed directly from a distance of about arms length, the linear features tend to stand out from amongst the confused cultivation patterns.

5.5 Recording of Interpretation

Interpreted detail was recorded by annotation on 1:500,000 enlargements of bands 5 and 7 made on stable-base material. Since these enlargements were later to be used in the map compilation, all interpreted details were accurately annotated in black ink. (See illustration 2).

5.6 Detail Interpretation

5.6.1 Urban Areas

Towns with a population of 15,000 and above can easily be identified. Those with lower populations than this become progressively more difficult to recognise as they decrease in size. The smallest village that was identified has a population of about 1000 persons, but this was only possible when viewed in conjunction with medium scale maps.

The ability to recognise an urban area depends upon its degree of contrast with the surrounding countryside. Most towns in the United Kingdom do not finish abruptly, but rather tend to thin out towards their edges where the houses and their accompanying gardens become larger. This makes it very difficult to define the exact limits of urban areas, while the smaller areas tend to merge with the surrounding cultivation patterns and become invisible.

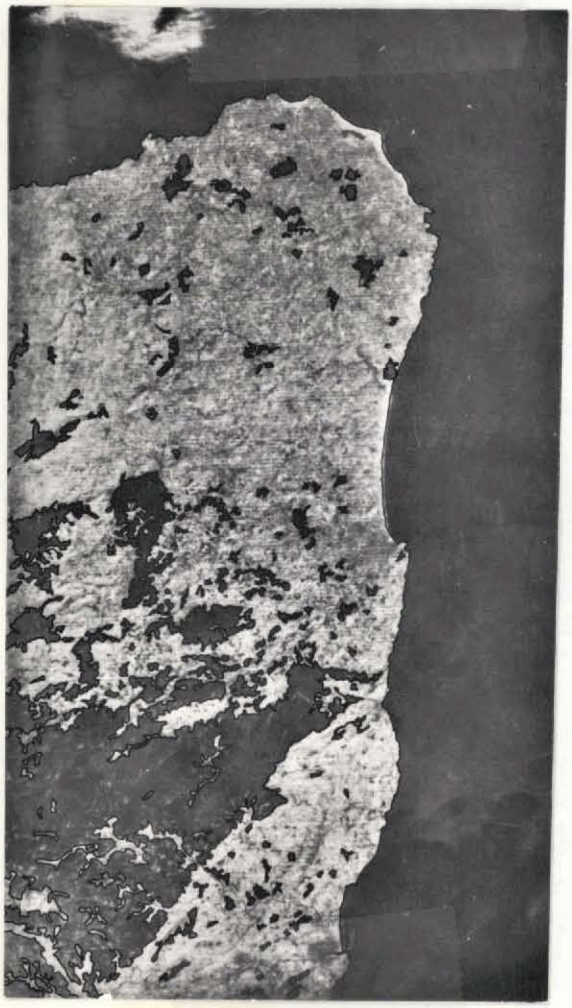
Urban areas are easiest to recognise on imagery taken in late spring and summer when the green crops are at full growth. At this period there is the greatest contrast between the urban areas and the surrounding countryside. During the late autumn and winter the fields are largely bare and appear very similar to the town. Larger urban areas tend to show a distinctive pattern of development, usually radial from a dense central area, but this is not always visible. Most large towns, particularly the older ones, also show a distinctive dark central area which corresponds to the older part of the town where the density of building is much greater. (See illustration 3).

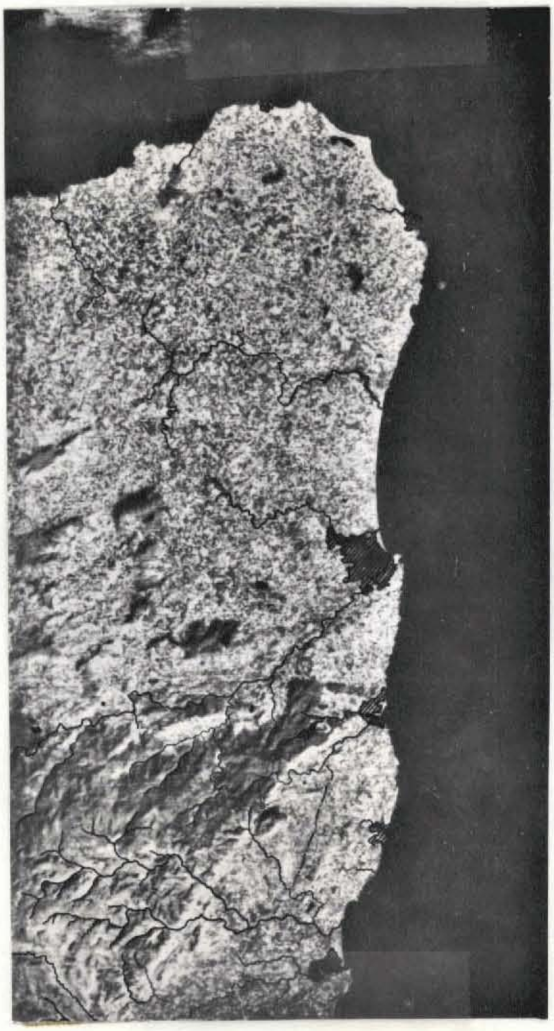
Urban areas may be most easily identified using black and white prints of spectral bands 6 and 7. It is sometimes an advantage to view band 7 simultaneously with band 5 in order to take advantage of the differing image signatures in the different spectral bands.

5.6.2 Road and Rail Communications

Railways of two or more tracks can usually be seen, although they

Image E-1231-10451. Scale 1:1,000,000



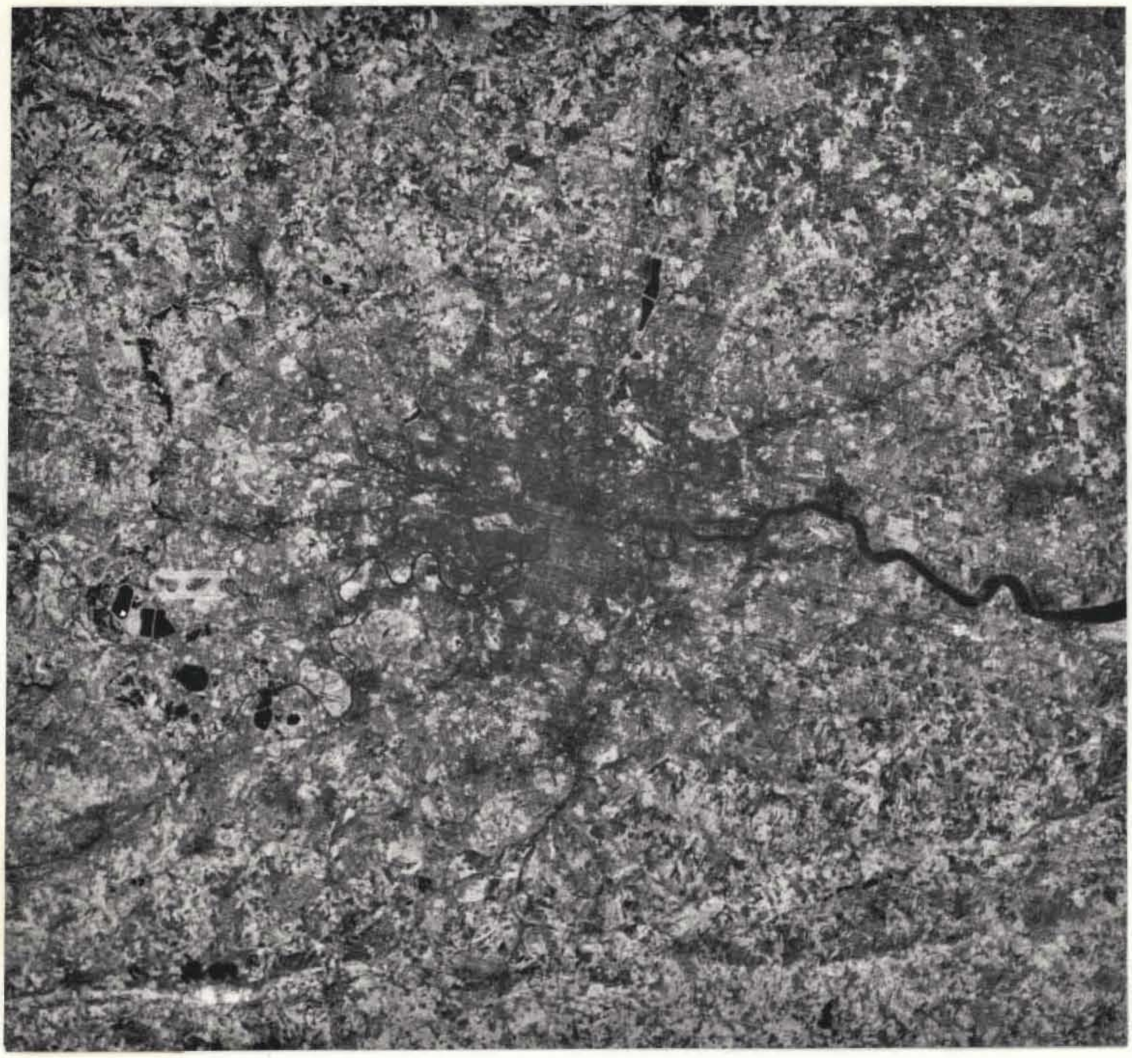


Examples of annotated prints used in compilation of Scotland.

(left) Band 5. Print annotated for vegetation. The small dark areas in the north are woodland,whilst the large area in the south is moorland. No sure method has been found to distinguish between the two.

(right) Band 7. Print annotated for urban areas and water features. The drainage pattern is more complete in the south where it is not confused by the cultivation.

Image E-1228-10293-7. Scale 1:500.000



This enlargement of the London conurbation shows the lack of any regular urban pattern and the very indistinct interface between rural and urban areas.

sometimes cease to be visible for no readily apparent reason. This may possibly be due to the lack of contrast between the grassed railway embankments and the adjacent fields. The actual width of the track is comparatively narrow and it is only the total width of the right-of-way from one boundary fence to the other which can be seen. Railways are usually confused with roads and the only possible way to tell them apart is by their straightness and gentle curves.

Major roads and motorways can sometimes be seen, but it is not known for certain which factors govern their visibility. Width is obviously one factor, but the widest of roads can disappear when it does not contrast sufficiently with the surrounding countryside. Roads can also become lost in the cultivation pattern when they follow the edges of irregularly shaped fields. Roman roads can sometimes be identified since they are straight and the field patterns are not continuous from one side of the road to the other. Modern roads however which are equally straight and wide, but which cut straight across existing field patterns, cannot usually be identified. One of the main problems with the identification of roads is the lack of completeness. (See illustration 4).

Roads and railways are most easily identified from black and white prints of bands 6 and 7 and more rarely 5.

5.6.3 Airfields

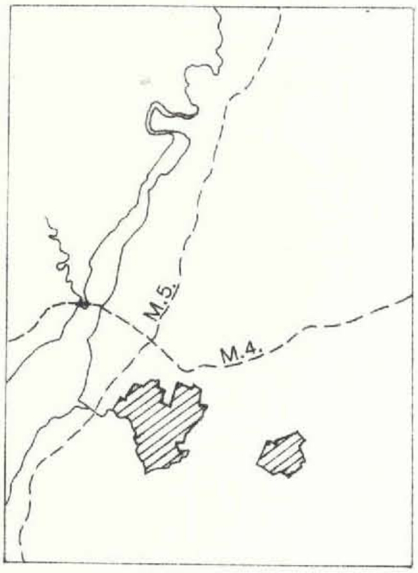
These usually stand out very clearly, the actual runways being visible even when the airfield has been disused for many years. This type of detail is identified most easily on black and white paper prints of spectral bands 6 and 7 and more rarely 5.

5.6.4 Forest and Heathland

Both forested areas and heathland, i.e. areas of gorse and heather, appear very similar on all imagery and are very difficult to differentiate with any certainty. Forest often appears slightly darker in tone, but there is not sufficient distinction to separate the areas with any certainty. Forestry plantations have distinct, often straight limits and fire-breaks can be seen running through them, whereas heathland has a very indistinct limit where it thins off into upland pasture. Deciduous woods do not show very clearly on imagery taken during the winter months, but they can be

PLATE 4

Images (centre) E-1031-10341-7, 23 Aug.1972. (right) E-1229-10352-7. 9 Mar.1973. Scale 1:1,00.000



Motorways are clearly visible on the centre image, but are very difficult to see on the right image.

PLATE 5

Image E-1228-10293-6. Scale 1:1,000,000

Identification of small linear features. The railway indicated by the arrow is 20 m. in width and is detectable by the disruption it causes to the cultvation pattern.

differentiated from arable land by simultaneous examination of spectral bands 5 and 7 under a stereoscope. (See illustration 2)

More information might have been extracted by a comparison of imagery taken at different seasons, but there was insufficient cover to permit this.

The extent of forested and heath areas is best defined using good quality false colour composite prints.

5.6.5 Cultivation

Arable land is composed of a confused pattern of relatively small fields, generally between 2 and 10 hectares in area and it is chiefly recognisable by this pattern. There is continuous change from one season to another and from one spectral band to another and any doubtful areas can be confirmed by reference to imagery taken at a different date and by simultaneous viewing of bands 5 and 7 under a stereoscope. Arable land can be fairly easily differentiated from other vegetation types using false-colour composite prints, but it cannot always be distinguished from some urban areas. (See illustration 1).

Upland pasture in the United Kingdom can be considered to be any land which is not arable, forested or heathland. The transition from arable to pasture land is a gradual one and an arbitary boundary usually has to be drawn between the two.

5.6.6 Coastal Features

The limits of the sea are most clearly visible on band 7, as are tidal mud flats and sand banks which are above water level. However shallow mud and sand banks can be seen on spectral band 5 which penetrates the water to a much greater depth. This band also clearly shows the plumes of suspended sediment at the mouths of the larger rivers.

5.6.7 Rivers, Canals, Lakes and Reservoirs

Rivers containing water down to a width of approximately 40 metres can be clearly identified. Below this size, the river itself is not longer visible, but its course can often be followed by its effect upon vegetation and landform. However, in areas of intensive cultivation, the vegetation right up to the river bank is not natural and this seriously effects the detectability of the river. A small river which meanders can also become 'lost' in the cultivation pattern. Generally, only the larger rivers can

be traced for their whole length through flat highly cultivated areas with any certainty. (See illustration 2).

Only the larger canals can be seen. Although much of Britain is covered by an extensive canal system, many of these canals are disused and overgrown and cannot be seen on the ERTS imagery.

Lakes and reservoirs are clearly visible down to a minimum size of about 5 hectares.

All water features are most clearly visible on spectral band 7.

5.7 Tests of Identification

During the initial famili risation period various interpretation techniques were tried and tested to check the validity of the results obtained.

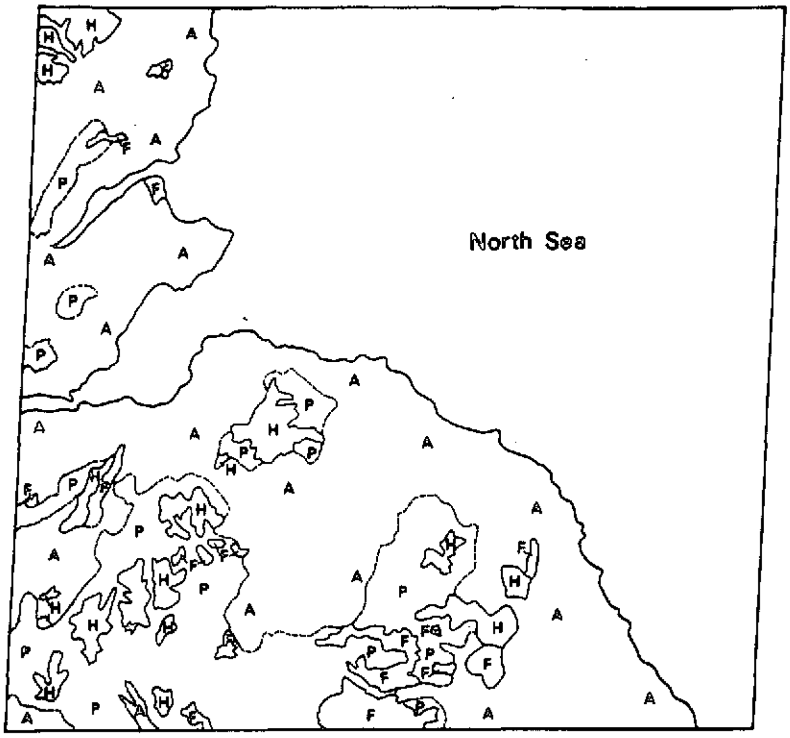
An image in south east Scotland (E-1231-10453) was interpreted in the laboratory for vegetation using a false-colour combination print and the same image was interpreted in the field. The two interpretations show very good agreement. The differences between them are mostly due to differences of opinion as to where the very vague boundaries should be placed and similar differences would probably be obtained from two independent photo-interpretations of the same area by different persons. (See Figure 11).

Vegetation was checked in the field as available maps do not show the details which were being interpreted. Checks were made upon the interpretation of other types of detail by comparison with Ordnance Survey maps at various scales and with any other source material which was available. Confusion was sometimes caused by the interpretation of very new details which were not on the published maps, but the Ordnance Survey maps generally proved to be a very reliable and complete source of comparative data and of course show much more detail than can ever be detectable on the ERTS imagery.

5.8 Summary of Interpretation Results

The ability to detect and identify an object on the imagery appears to depend upon a combination of such factors as object size, shape, contrast, and surrounding patterns of detail. Image resolution limits the minimum object size and change of contrast which can be recorded, but most features must be considerably larger than the minimum and distinctive in shape or pattern of associations before they can be interpreted correctly. The interpreter is often confused by a mass of redundant and confusing tonal differences which

FIGURE 11



Field Interpretation

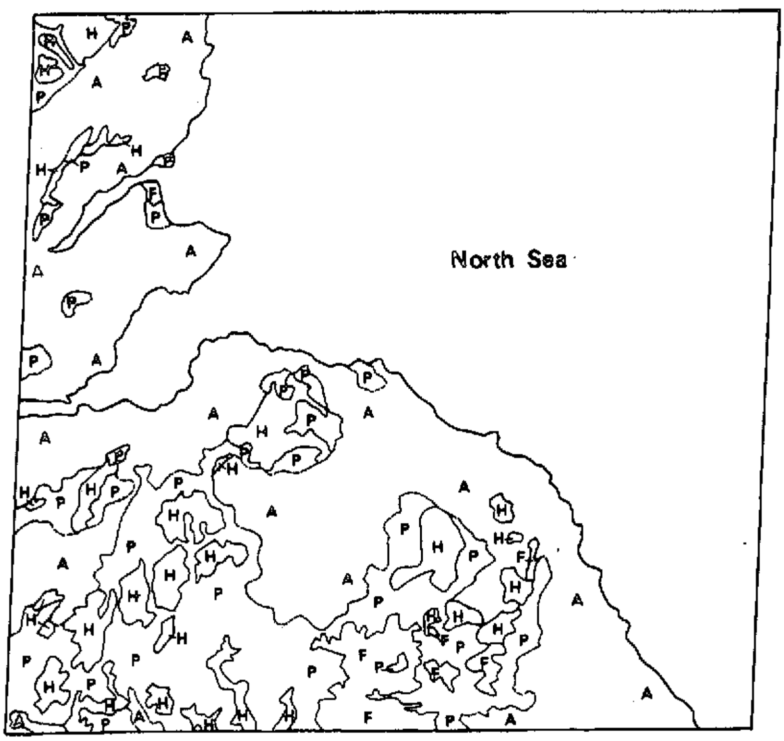


Photo Interpretation

Comparison between field and photo interpretation of vegetation of image E-1231-10453 in S.E. Scotland

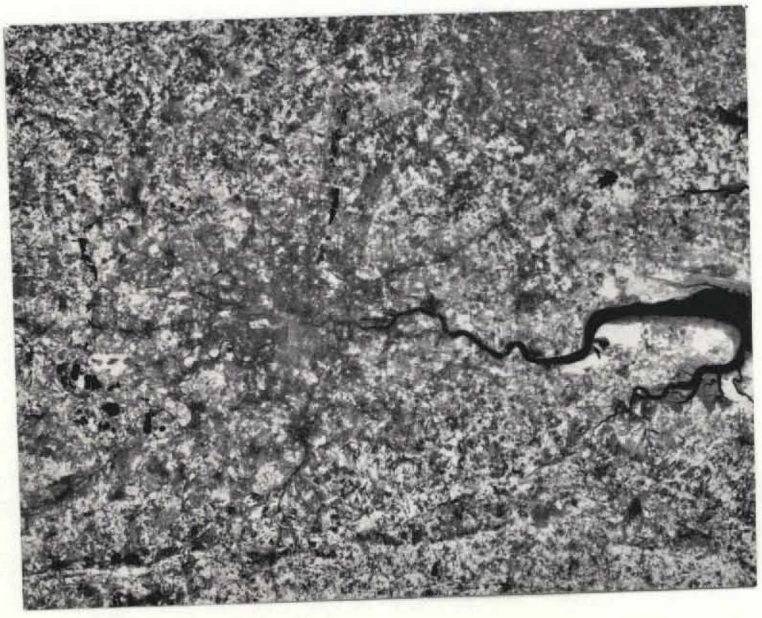
obliterate meaningful tones and patterns. Generally the smallest discrete object of high contrast against its surroundings which can be detected is about 100 metres in diameter. However even smaller objects of exceptionally higher contrast against their background can be recorded on the imagery. The multispectral scanner records the average signal strength reflected by an area about 80 x 80 metres square, known as a pixel. A smaller object of very high contrast can change the average signal strength of the whole pixel sufficiently to register as a change of tone. These minimum recordable objects could only be identified with the assistance of other sources of ground truth data. The feature must be at least twice this size to stand a chance of interpretation from the imagery alone.

Linear features well below the recordable threshold appear quite clearly in some circumstances but this is not consistent. Fairly wide features such as motorways can often be detected by the human eye as a disjointed string of discrete points. But even when the feature itself is too narrow and of too low contrast to register even as an intermittent chain of distinctive tone, it may still be discerned where there are changes of land use on either side. (See illustration 5).

The United Kingdom is probably not a very favourable test area for ERTS imagery interpretation. Besides the relatively poor image quality caused by climatic conditions (see illustration 6) the pattern of land use is much too varied and the average parcel of land too small. The imagery displays this faithfully by a speckled appearance, much of which defies interpretation. In more uniform landscapes with better weather conditions ERTS imagery interpretation may be more rewarding.

Image E-1228-10293. Scale 1:1,000.000

Band 5. Atmospheric pollution obscuring detail around London. Note the plumes of haze drifting southwards.



Band 7. Haze can still be seen partially obscuring the river in central London.

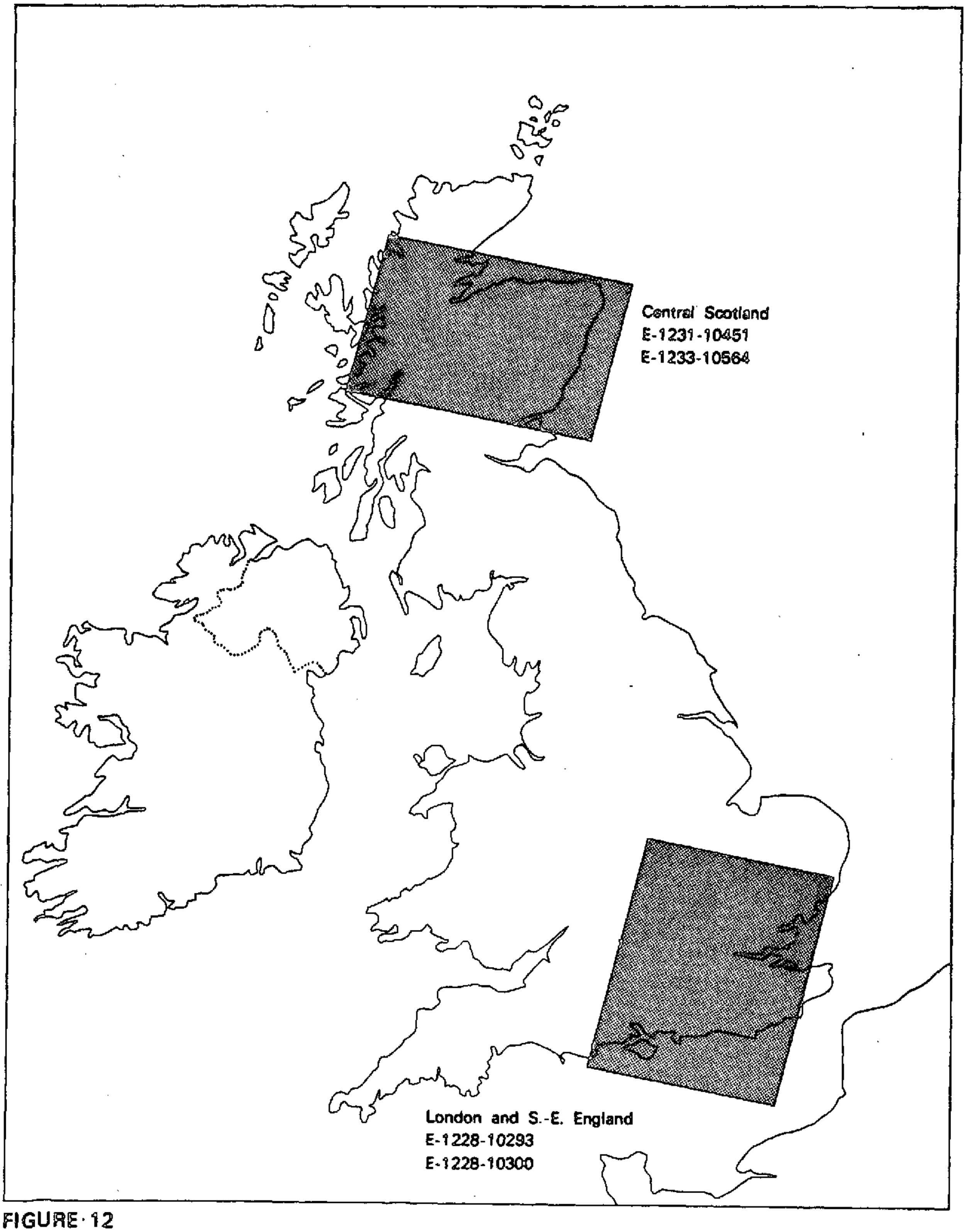


FIGURE 12
Compilation Test Areas

6. MAP COMPILATION

6.1 Compilation Methods

During the image interpretation stage of the study, the interpreted detail had been annotated on 1:500,000 enlargements of the imagery. These enlargements, produced on stable-base material from the NASA 1:1,000,000 film positives, were annotated and then reduced back down to 1:1,000,000 again, scaling on the original NASA 1:1,000,000 film positives for accuracy. The reductions were made on a Lithotex Copy Process Camera capable of producing results accurate to $\pm$ 25 microns. These 1:1,000,000 scale annotated negatives were used as source material for the map compilation.

Two methods of compiling the map from these negatives were considered. The first method involved plotting the detail with a first order photogrammetric plotting instrument (a Wild A8 stereoplotter). Since this instrument is designed for plotting from a stereoscopic pair of photographs, it is more convenient although not essential to work from a pair of ERTS images. Two prints of the same image were preferred and after trying various combinations of bands, a false-colour combination film transparency (bands 4, 5 and 7) paired with a black and white positive film transparency of band 7 was chosen.

This combination proved to be the best for interpretation in the instrument, but it was found that the restricted field of view and six times enlargement of the optical system made the recognition of some features very difficult. This could only be overcome by using the annotated 1:1,000,000 negatives in the instrument which meant that it was simply used for tracing the annotated detail. Whilst this is a very accurate method of tracing, it was considered that the increase in positional accuracy did not warrant the use of such expensive equipment or such time consuming methods.

The second method of compilation, which was later adopted in preference to the first, involved direct tracing from the annotated negatives over a light box. This method is sufficiently accurate for the purpose if it is performed with care and has the advantages of being simple and using little apparatus.

Two different methods were used to position the detail. On the Central Scotland compilation, the positioning of the detail is entirely dependent upon the graticule cuts on the margins of the images. A graticule

was constructed at a scale of 1:1,000,000 on the Ordnance Survey National Grid projection. The two images concerned were first fitted one to another by the detail. These joined images were then fitted by their graticule ticks to obtain a best mean fit onto the graticule. The detail on the South-East England compilation was positioned onto a grid by means of control points obtained from the block adjustment. The graticule for this compilation was also positioned on the same grid.

6.2 Positional Accuracy of Compilations

Because of the different methods which had been used in the two compilations, different methods of checking the positional accuracy of each area had to be adopted.

Central Scotland

A number of points of detail on the compilation were identified on the O.S. 1 inch maps and the National Grid coordinates were read. An arbitary grid was laid over the compilation and the compilation coordinates of the same points of detail and of four graticule intersections were recorded. The compilation coordinates were then subjected to a rotation and change of origin to give a least squares mean fit onto the National Grid coordinates. The residual errors on the check points show the relative positional accuracy of the detail and those on the graticule intersections show the absolute positional accuracy.

The relative positional accuracy measured on 17 points gave a root mean square error of 480 metres with a maximum of 787 metres (see Figure 13).

The distribution of errors is as follows:

Error	No. of Points	Percentage of Points
0 - 100 metres	1	6 per cent
101 - 200 metres	1	6 per cent
201 - 300 metres	2	12 per cent
301 - 400 metres	2	12 per cent
401 - 500 metres	3	17 per cent
501 - 600 metres	5	29 per cent
601 - 700 metres	2	12 per cent
701 - 800 metres	1	6 per cent

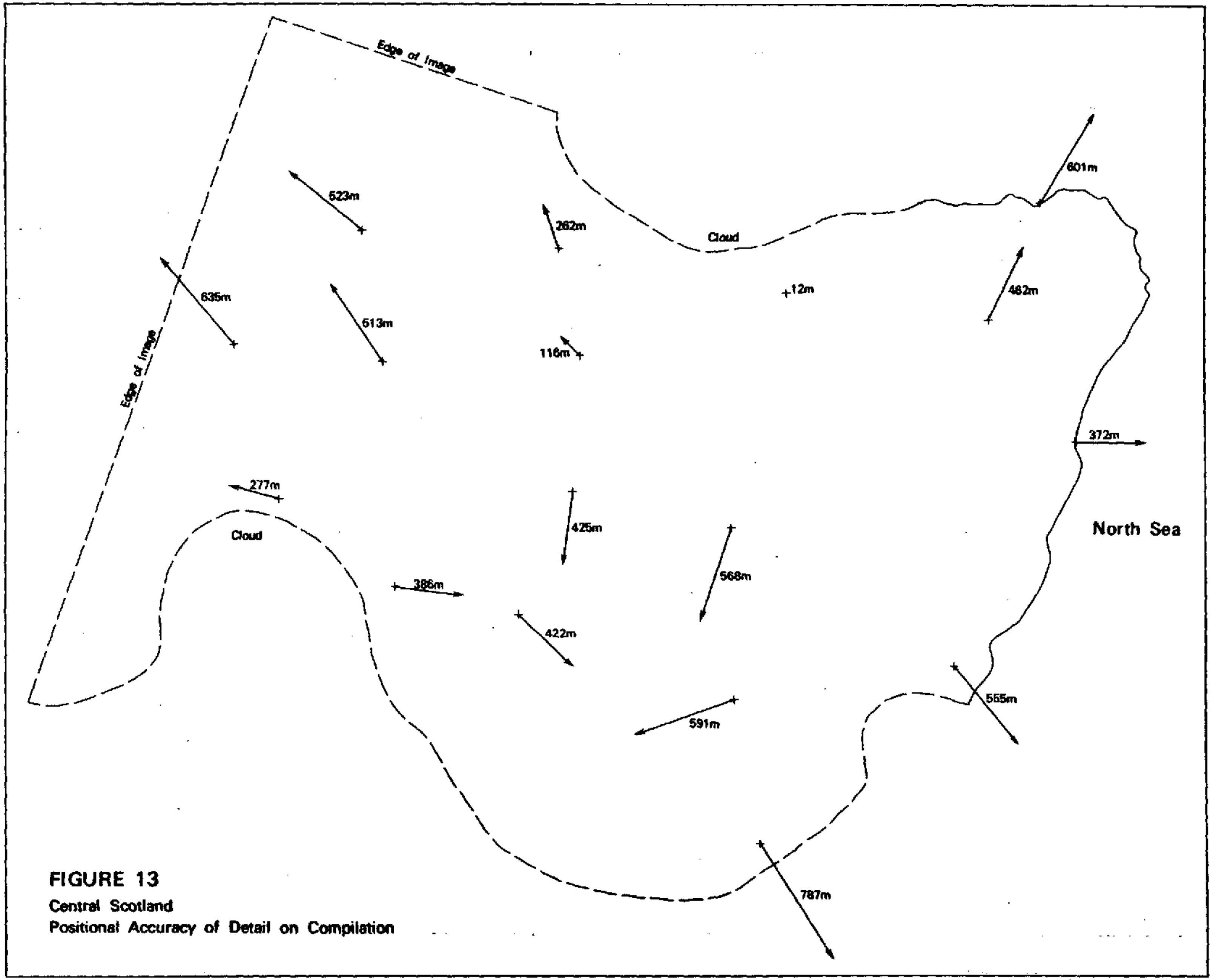


FIGURE 13
Central Scotland
Positional Accuracy of Detail on Compilation

The absolute positional accuracy measured on four graticule intersections shows a r.m.s.e. of 1474 metres (see Figure 15).

South-East England

A number of points of detail were selected and the National Grid coordinates were recorded as for the other area. However, since this area had been compiled onto control points which had been plotted on a grid, final compilation coordinates could be read directly off this grid without any computation being necessary.

The detail positional accuracy as measured on nineteen check points gave a r.m.s.e. of 272 metres with a maximum of 471 metres. (See Figure 14).

The distribution of errors is as follows:

Error	No. of Points	Percentage of Points
0 - 100 metres	0	0 per cent
101 - 200 metres	6	32 per cent
201 - 300 metres	5	26 per cent
301 - 400 metres	6	32 per cent
401 - 500 metres	2	10 per cent

The positional accuracy measured on four graticule intersections shows a r.m.s.e. of 148 metres. (See Figure 15).

The positional accuracy of the South-East England compilation gives a very satisfactory result, well within required tolerances.

The root mean square error on the check points is only 100 metres worse than that obtained from the block adjustment and coordinates can only be read from the compilation to an accuracy of $\pm$ 100 metres.

The results obtained for the Central Scotland compilation are not so good. However this is to be expected since the images were fitted by the marginal graticule ticks and these show a difference of up to 400 metres when compared to a graticule constructed on the O.S. National Grid projection. It is obvious that the method used in this compilation was not very satisfactory and that better results would have been obtained by performing a block adjustment, even if it was done on the minimum of control.

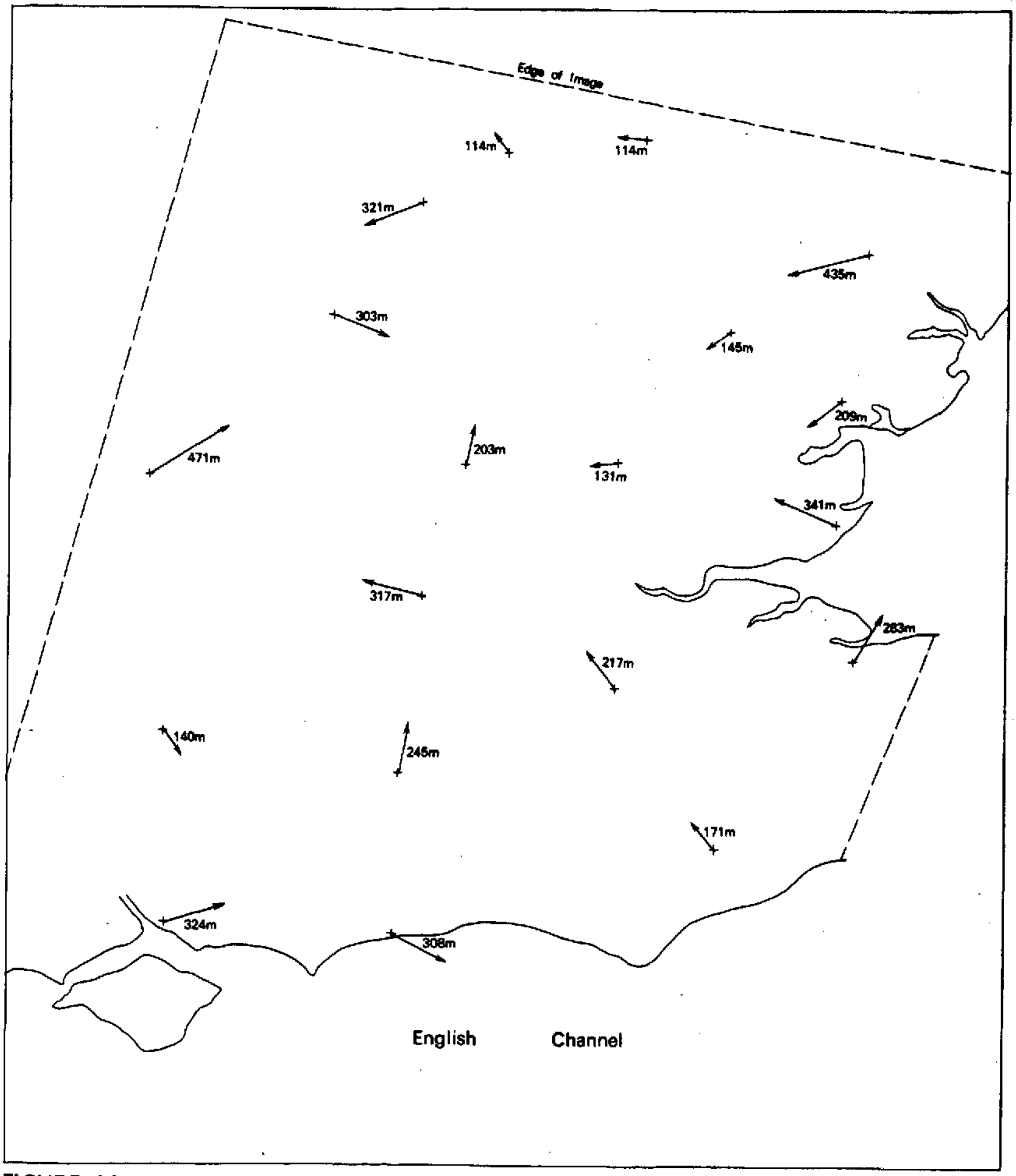


FIGURE 14
South-East England
Positional Accuracy of Detail on Compilation

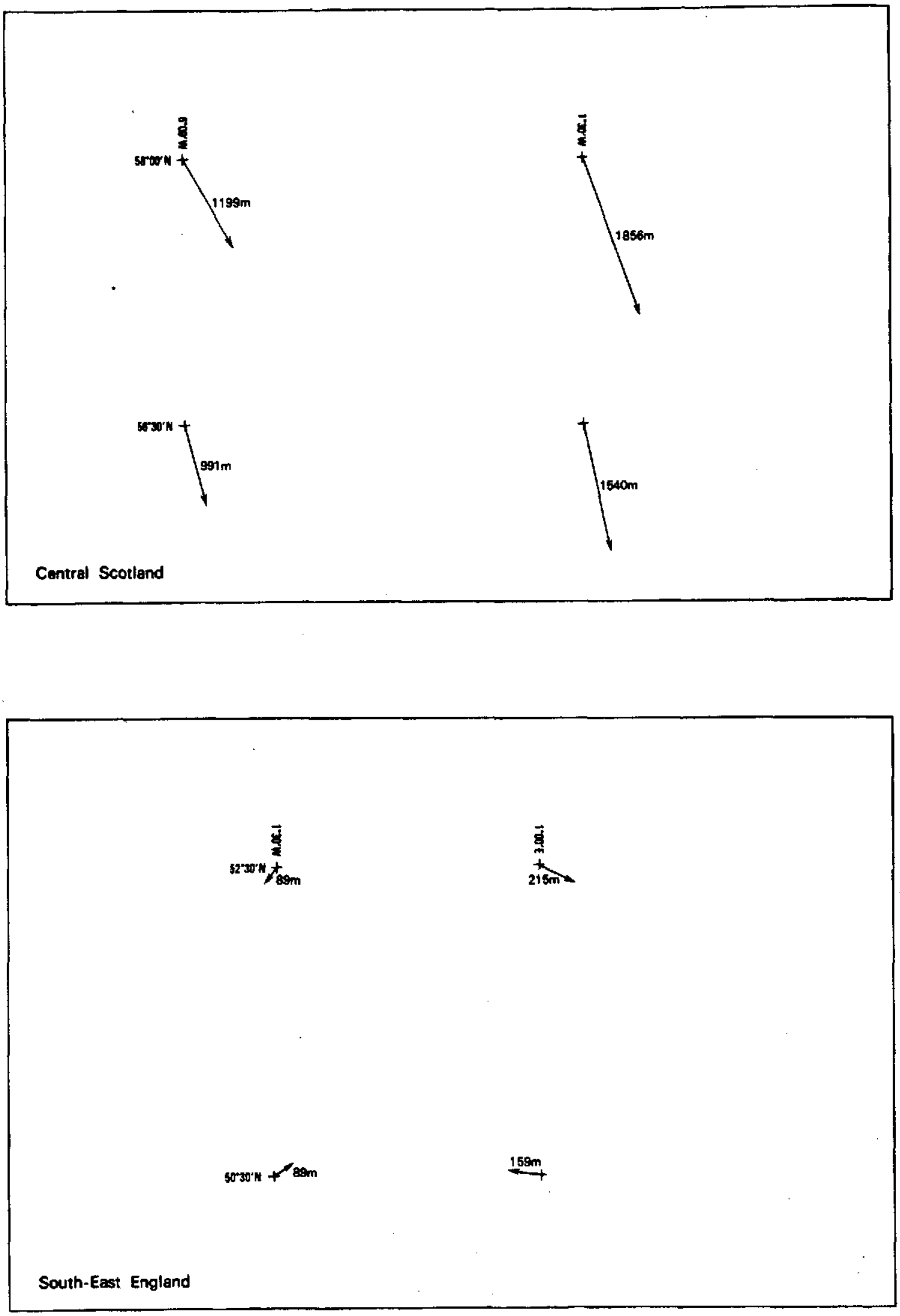


FIGURE 15
Positional Accuracy of Graticule on Compilations

7. UNSEEN INTERPRETATION OF TEST AREAS

The interpretation of topographic detail in the selected test areas of Scotland and South-East England was carried out without reference to other sources of ground truth data. The results were then compared against published Ordnance Survey maps and other available sources and the findings are summarised below.

7.1 Central Scotland (See Plates 8 and 10)

Coast-line. This shows very good agreement in most areas. There are some discrepancies in the southwest corner which are probably due to confusion caused by the clouds. A notable difference can be seen at the mouth of the Moray Firth, where there is an area of tidal mud-flats.

Lochs and Reservoirs. It has been found that the differences here can be almost entirely explained by the omission from the O.S. map of small lochs and new reservoirs. The ERTS plot shows more small detail than the map.

Rivers. The interpretation of rivers is poor in the north east of the area where they are lost in the intensive cultivation pattern. It is much better on the remainder of the area, although there are probably very few cases where the actual water is visible. These rivers are generally infered from the vegetation changes which mark their course. There is a tendency towards confusion wherever two streams run down the opposite sides of a watershed. It is often difficult to determine the exact position of the watershed and some tributaries have been wrongly connected so that they appear to flow in the wrong direction.

Urban areas. The major urban areas which almost entirely fall on the east coast are well delineated. Over the remainder of the area, they are too small and scattered to be detected, with the exception of Inverness at the head of the Moray Firth.

Communications. Very few roads and railways could be seen. Roads in this area tend to be fairly narrow and seldom have any marginal hedges or lines of trees. The only communications which were found are in the south-east of the area and consist of two short lengths of road and another which is a road with a railway running parallel.

Vegetation. A composite plate has been made for the comparison of areas of vegetation. It was made by combining the limits of forest and moorland as extracted from various sources in order to produce an up-to-date

map against which the ERTS plot could be checked. The two compare favourably, but there is a tendency in some areas to interpret moorland as pasture. This may be due to the presence of very rough pasture which is intermediate between pasture and moorland.

7.2 South-East England (See Plates 7 and 9)

Coast-line. There is very good agreement between the O.S. map and the plot.

Lakes and reservoirs. As with the Scottish plot, this one shows many more small lakes than are shown on the O.S. maps. There are also many new reservoirs and flooded gravel workings which are not on the map.

Rivers. The interpretation of rivers is not good in this area. The River Thames which is wide enough for the water to be seen on the imagery is accurately depicted. However, other smaller rivers are mostly hidden by the cultivation patterns and cources of some of the streams shown are completely wrong.

Urban areas. These are well depicted and show some considerable areas of new development which are not on the O.S. map. There are however anomalies on the southern edge and to the east of London. These can probably be explained as areas of relatively thin development which have been confused with the surrounding cultivation pattern.

Railways. Although many railway lines have been shown, the network is by no means complete. There appears to be no correlation between the lines shown and their width. In some cases, lines which consist of two tracks have been depicted while others which have four or more tracks cannot be seen.

Roads. The road network in this area is much too dense to be shown at 1:1,000,000 scale and has been greatly conventionalised on the O.S. maps. While there is a tendency for the interpretation to follow a rule that the smaller the road the less its chance of being seen, this rule by no means applies in every case. In one area, a six-lane motorway has not been found while quite nearby a roman road has been shown which is now no more than a farm track and a line of trees. There is not any way in which roads in this area can be effectively classified since the national

road numbering system is dependent upon the relative importance of the roads and does not necessarily bear any relationship to their size. It is therefore impracticable to attempt to define which roads should be visible and obtain an objective view of the completeness of road communications interpreted from the ERTS imagery.

Airfields. All the major airfields in the area have been shown. However there are a number of military airfields in the area, most of which date from about 1940 and many of which have been disused for many years. Some of these have been found, but on the other hand, some small airfields which are in use cannot be seen.

Vegetation. The vegetation in this area is very different from that of the Scottish areas. It is largely arable, but with a thin scattering of woodland which gets thicker towards the south. It is mostly deciduous woodland and even the larger units consist of small areas interspersed with some areas of cultivation. This may partly account for the differences between this plot and the map.

7.3 Summary of Findings

The results of the comparison between the Ordnance Survey maps and the ERTS plots bear out the contention that the interpretation of detail from the imagery can never be complete enough for the purposes of mapping, but that it can be a valuable source of map detail when used in conjunction with other available sources.

8. GROUND HEIGHT DETERMINATION

The MSS imagery cannot be used to measure ground height variations with usable accuracy. By conventional photogrammetric techniques, heights are derived from measurements of parallax differences between overlapping photographs which have been taken from different perspective viewpoints. The MSS imagery provides neither the internal dimensional stability of the normal photographic image nor, except in the more northerly latitudes where there is a considerable lateral overlap between passes, the necessary stereoscopic overlap. Even with the high dimensional stability of photographic images, the accuracy of photogrammetric determination of heights from an altitude of 950 km would only be suitable for contouring to normal specifications at a vertical interval of about 800 m.

In many parts of the world, the relative ground heights are so small that no stereoscopic effect is appreciable and random positional errors in the scanned images can give a false impression of small local height changes. However, despite the fact that the stereoscopic impression of relief is too small and unreliable for accurate height measurement, it should not be ignored. It can give valuable aid in the interpretation of terrain features, particularly water-courses in mountaneous areas, and every advantage should be taken of it where possible.

Whilst height cannot be measured, the imagery does provide a visual impression of relief in mountainous terrain which the cartographer can develop as a hill-shading plate. (See Section 9).

9. PICTORIAL PORTRAYAL OF RELIEF (See Plate 11)

Experiments were carried out to assess the possibility of obtaining a pictorial portrayal of relief by means of half-tone plates produced directly from the ERTS imagery and suitable for final lithographic printing. A single image covering part of Central Scotland (E - 1233-10564-6) was chosen for these tests.

For the initial tests, half-tone positives were made directly from a 1:1,000,000 scale continuous tone ERTS negative, using a 150 magenta contact screen. While moderately successful the results all lacked the required contrast and 'sparkle' associated with conventional hill shading methods. Moreover, the fact that all shadow areas appear on the N.W. face of mountain features which is the opposite of the normal cartographic convention, added to the generally displeasing result.

Further tests were therefore carried out, this time using a continuous tone positive of the ERTS frame from which half-tone relief negatives were produced. This had the effect of reversing all shadow sides to the S.E. face of the relief features, the treatment normally adopted in conventional hill shading techniques. The quality of the half-tone negative was further improved by introducing additional contrast during the half-tone process by changing the basic density range. This half-tone negative was subsequently considered and used as a positive.

Following the more successful results obtained by the above techniques, it was decided to further enhance the black half-tone relief plate by introducing a tint of magenta in the shadow areas plus a series of hysometric tints obtained from existing sources in order to increase the impression of relief.

Final combined line and tone positives were prepared suitable for 4-colour lithographic printing in black, blue, yellow and red as follows:

Black Plate	Half-tone relief
Blue Plate	Drainage - solid line Hypsometric tints - 10% and 20%
Yellow	Hypsometric tints - 10%, 20% and 30%
Red	Half-tone relief on shadow side

10. CONCLUSION

The results of this investigation suggest that ERTS imagery can have some application for topographic mapping at 1:1 million scale.

In developed regions of the world already topographically mapped at larger scales, the imagery may prove useful for updating maps at 1:250,000 or smaller scales in order to incorporate such major developments as new motorways, reservoirs and rapid urban growth. This seems unlikely to be a major application, as much of this type of information can be abstracted from the admittedly more cumbersome source of engineering design plans.

The most promising cartographic application of ERTS imagery would appear to be for original mapping at around 1:1 million scale of the remoter and little developed parts of the world which have not been adequately mapped even at this scale and which are unlikely to justify or attract the necessary funds for conventional aerial survey mapping at 1:100,000 scale or larger. Conventional aerial survey involving flying photography, establishing geodetic control, photogrammetric plotting, field verifying and cartographic drawing and printing, is extremely efficient for map production at 1:100,000 scale or larger, but very little saving in time and cost is achieved by reducing the original mapping scale from 1:100,000 to 1:250,000 or smaller.

The geometric accuracy of the ERTS imagery is suitable for 1:1 million mapping and appears to lend itself to block adjustment using sparsely scattered control. Further tests with large blocks are needed to confirm this. The unaided interpretation of topographic detail from the imagery is inadequate for mapping even at 1:1 million scale in most landscapes, but may well provide an incomplete skeleton of precisely located features which can be augmented with details from other sources of information.

It is unfortunate that many of the regions of the world which require original mapping at 1:1 million scale coincide with regions of persistent cloud cover where ERTS imagery is either patchy or totally lacking.

In addition to the rigorous requirements of topographic mapping ERTS imagery can provide valuable map-substitutes in the form of uncontrolled or controlled mosaics, enlargements and annotated reconnaissance maps. As long as the imagery continues to be made available at reproduction cost or less, there are numerous applications, some marginal, for which it can be used. The imagery is already being used for field and aircraft navigation and the preparation of base maps for thematic mapping and regional planning.

11. APPLICATION OF ERTS IMAGERY TO ATLAS AND SMALL SCALE MAP PRODUCTION

11.1 Observations by John Bartholomew and Son. Ltd.

The geometric accuracy of the systems corrected imagery (SYC1) has been proved and is more than adequate for map revision purposes. The precision of orientation, the (relative) absence of scale distortion and the minimal requirement of only one well-defined control point for an absolute fix of the entire graticule net provide a remarkable facility for checking ground-truth information on existing maps.

The two main limitations to the application potential of ERTS imagery are, of course:

(1) The inability to penetrate cloud cover, which in many parts of the world is both extensive in area and almost continuous in time, and;

(2) the tone dot size which gives a 'pixel' area coverage of 80 metres square (80 x 80 m) giving restricted definition which does not allow other than large features, whether natural or man-made to be seen or identified with confidence. The availability of retrievable photographic film should improve this situation considerably.

Current aeronautical charts show vast tracks of the Earth's surface to be inadequately mapped, and despite considerable recent progress in large and small-scale topographic mapping programmes in many areas. The availability of derived mapping (at 1 million and 1:500,000) on which commercial cartographers depend for general reference map and atlas compilation, lags far behind. In other parts of the world security strictures prevent the release of existing mapping. For all these categories ERTS imagery can prove invaluable as a means of overcoming deficiencies of available conventional material.

11.2 Observations by George Philip and Son Ltd.

(a) The results of the test show that ERTS can be used as a source of information for the revision of small-scale maps in atlases. 1:1M. is a larger scale in many atlases and even the largest scale in many educational atlases, the width of lines and symbols therefore represent many kilometres on the ground and the accuracy obtainable from ERTS is well within these limits. Clearly, where there are good topographical maps and good derivations from them at scales of ¼M, ½M, 1M, 2½M, which are the usually convenient scales of sources for small-scale atlas mapping, ERTS will be able to add little information. On the other hand, where topographical maps and derivations are not good, for example in many large parts of N. Canada, Central and S. America, North and Central Africa and Central Asia, ERTS would be an invaluable new source of information.

(b) In addition, where there are good basic topographical maps which are badly out of date through lack of revision over many years or even decades, the new up-to-dateness of ERTS is also a valuable new source for small-scale mapping, which normally needs to be produced very quickly and which is expected by the user to be up-to-date. Thus, new roads, railways, reservoirs etc. are expected to be shown in their correct positions, shapes and alignments. Information on the existence of such features is relatively easily obtained, but often not on the accurate shape, position and alignment.

(c) ERTS will also provide the means of making entirely new maps, at least of cloud-free areas, without reference to existing topographical maps except as a source, together with other sources, of information such as populations of settlements, names of settlements and physical feastures, communications, economic developments such as mines, etc.

(d) In small-scale mapping the indication of orographical relief is a special problem and is often assisted by

artists' rendering of steep slopes and escarpments by hill-shading. This highly-skilled interpretation of the physical landscape will be helped by the ERTS imagery. It is possible, however, that the imagery may provide the hill-shading directly or nearly directly after a relatively easy and quick improvement of the imagery by some artists' re-touching. This would be a significant saving in the cost of producing hill-shading and would improve the standard generally and especially the consistency of hill-shading.

(e) With a proper choice of the right bands of imagery, new backgrounds in attractive realistic colourings will be possible by three or four colour separations of the imagery. It will also be possible to choose the background according to the season required e.g. in northern latitudes in spring, or summer, or autumn or even when snow-covered in winter. The Mediterranean areas look quite different at the end of the winter than after the scorching of a long summer; the steppe areas in the spring or at harvest time; the monsoom lands when dry or in flood and so on.

(f) ERTS will also be of much educational value and of general interest as chosen examples of typical areas and features, with the associated derived maps, for courses in map-reading; to supplement traditional maps in atlases and to accompany thematic maps, for example geological maps and mineral exploitations.

APPENDIX

MAP ILLUSTRATIONS

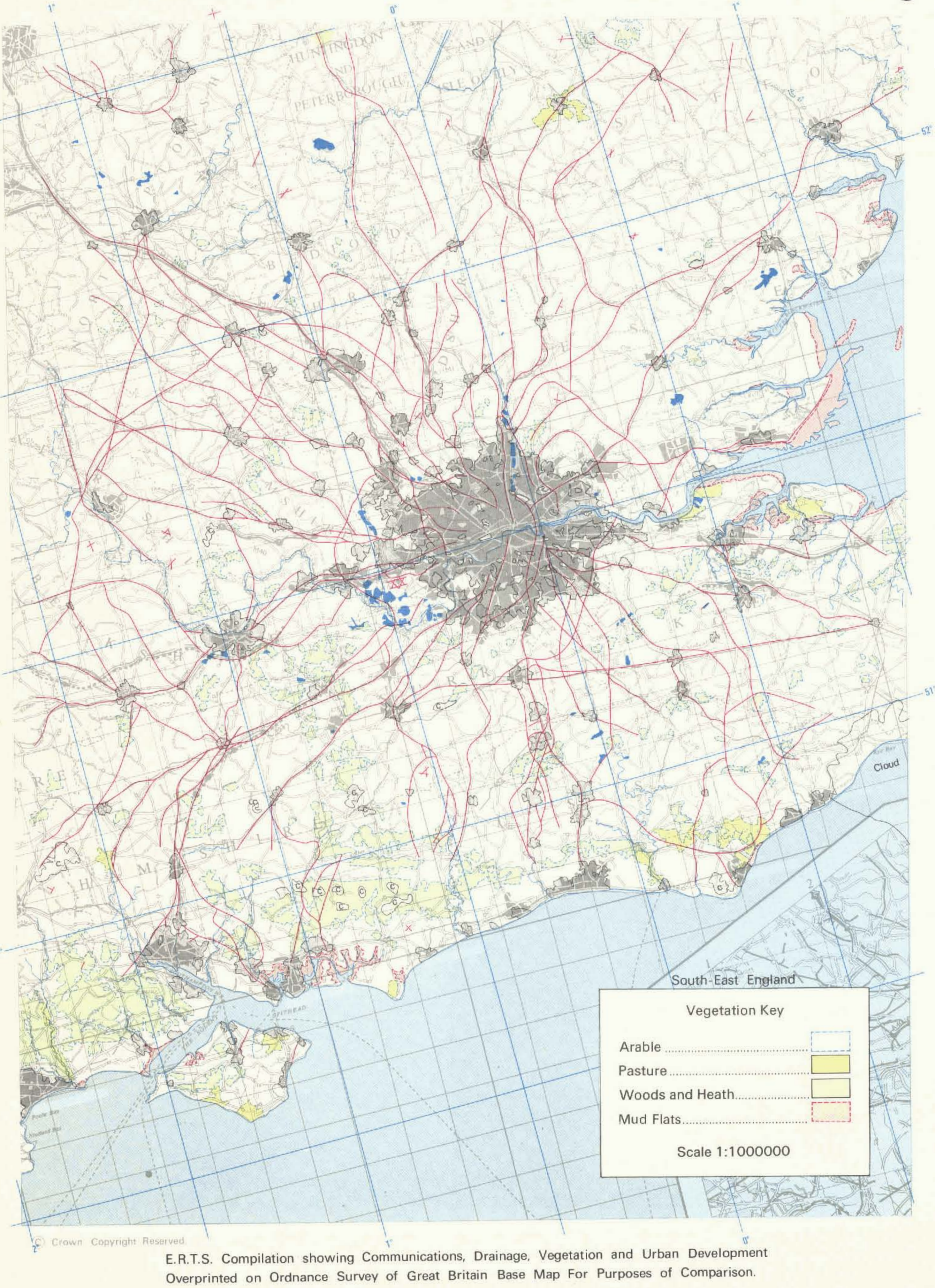
APPENDIX

MAP ILLUSTRATIONS

Plate 7	ERTS Map of S.E. England. ERTS compilation of the S.E. England test area overprinted on reductions of the Ordnance Survey base material for comparison of detail.
Plate 8	ERTS Map of Central Scotland. ERTS compilation of the Central Scotland test area overprinted on reductions of the Ordnance Survey base material for comparison of detail.
Plate 9	Diagram Showing Existing Vegetation in S.E. England. Diagram produced from existing map sources for comparison of areas of vegetation with similar detail shown on Plate 7.
Plate 10	Diagram Showing Existing Vegetation in Central Scotland. Diagram produced from existing map sources for comparison of areas of vegetation with similar detail shown on Plate 8.
Plate 11	ERTS Relief Map of Central Scotland. Image 1233-10564-6 with enhanced shadows and hypsometric layers added to give a pictorial impression of relief.

COMPILATION NOTE

For purposes of comparison between detail interpreted from the ERTS imagery and existing ground truth, compilations of the Ordnance Survey 1:625,000 scale Route Planning Maps, 1970 edition, were photographically reduced to 1:1,000,000 scale.



E.R.T.S. Compilation showing Communications, Drainage, Vegetation and Urban Development Overprinted on Ordnance Survey of Great Britain Base Map For Purposes of Comparison.

ORIGINAL PAGE IS OF POOR QUALITY

(8)

E.R.T.S. Compilation showing Communications, Drainage, Vegetation and Urban Development Overprinted on Ordnance Survey of Great Britain Base Map For Purposes of Comparison.

FOLDOUT FRAME 1

ORIGINAL PAGE IS OF POOR QUALITY

FOLDOUT FRAME 2

ORIGINAL PAGE IS OF POOR QUALITY

Areas of Woods and Heath extracted from Existing Sources for Comparison with Compilation.

Areas of Woods and Heath
extracted from Existing Sources
for Comparison with Compilation.

ORIGINAL PAGE IS
OF POOR QUALITY

Layer Tinted Relief Plate Produced from E.R.T.S. Image.